APPLICATION OF GIS TECHNIQUES AND AHP FOR RANKING SOLID WASTE DISPOSAL SITES

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by

DIPANJAN SENGUPTA

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Department of Civil Engineering
Indian Institute of Technology Kanpur
India

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CERTIFICATE

It is certified that the work contained in the thesis titled *Application of GIS Techniques and AHP for Ranking Solid Waste Disposal Sites* by *Dipanjan Sengupta* has been carried out under our supervision.

Dr Vinod Tare
Assoc Professor

Dr Onkar Dikshit
Asst Professor

Department of Civil Engineering
Indian Institute of Technology Kanpur
KANPUR - 208016

April, 1997

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ABSTRACT

Geographical Information Systems (GIS) represent a moderately recent development in the field of spatial database management and the capabilities of a GIS package to measure, monitor, map and model spatial data constitutes one of its characteristic features. It is this feature that warrants the application of these systems in the field of environmental planning and management, and assist decision-makers in confronting the complex real-world problems of spatial nature. In India however, the applications of GIS are rather limited, particularly in the field of environmental decision-making. This thesis provides a comprehensive introduction to GIS. The capabilities of these systems have been illustrated by employing them to address a typical problem of environmental management, namely, preliminary identification of sites suitable for solid waste disposal in a particular study area (Kanpur city). Disposal site selection is based on various considerations and as such it involves multi-criteria decision-making. The factors that were considered for preliminary site selection were broadly classified as: the exclusionary criteria and the non-exclusionary criteria. Physical and legal restrictions constituted the exclusionary criteria while the non-exclusionary criteria included: terrain characteristics, hydro-geological/geological characteristics and some other environmental considerations based on aesthetics and hygiene. The necessary ground information were acquired to prepare the databases in a GIS environment. The Integrated Land and Water Information System (ILWIS) package was used for the study. The potential sites were identified and ranked using the Analytic Hierarchy Process (AHP). The non-exclusionary criteria were decomposed to higher levels of details and AHP was applied to carry out pair-wise comparison of the elements in each of the levels to finally yield the ranks. The sites were ranked in four grades, with the first rank implying the best suitability for solid waste disposal.

Keywords: *Geographical Information Systems, Analytic Hierarchy Process, Solid Waste Management, Spatial database.*

1. PROLOGUE

Centuries before the Christian era, Babylonians drew maps on clay tablets. of which, the oldest specimens found so far have been dated about 2300 BC. That is the earliest positive evidence of the graphic representation of the Earth. It is assumed that man's interest in exploration and recording his environment goes back much further and that it began among non-literate peoples. This interest as such, is allied with geography, in its concern with the broader aspects of the Earth and its life. In early times, cartographic efforts were more artistic than scientific and factual and that is perhaps what inspired Jonathan Swift to write the following lines:

So geographers, in Afric maps.
With savage pictures fill their gap,
And o'er unhabitable downs;
Place elephants for want of town.

But early maps certainly were very much more than just the products of early man's artistic flights of fancy. They were the records, in rudimentary forms, of one of man's most primitive and deathless quests: information about his physical neighbourhood. The annals of history, are strewn with evidences of this, almost obsessive, quest of the human mind. With advancement of civilisation, the definition of *neighbourhood* gradually acquired global dimensions and spatial information were no longer confined to maps, but transcended to an instrument to measure, monitor and model the physical environment.

The contemporary time is likely to be looked back in future history as the age of *information revolution*, and the reflection of this revolution in spatial database management comprises of the tremendous technological advances, made during the past few decades, in human capabilities to encode, record, reproduce and disseminate spatial information. All these advances have made these information a new basic resource, that supplements the familiar natural resources of matter and energy. Accumu-

lated knowledge takes on an entirely new meaning and significance as techniques for mining, storing, sharing and using spatial information in new ways are learned.

One such moderately recent developments, in the field of spatial database management, are the Geographical Information Systems (GIS) and the capabilities of these systems to map, monitor, measure and model spatial data are exemplary. Data of environmental parameters represents an essential example of spatial data. Environmental planning can be regarded as a multi-criteria decision-making process whereby different considerations, aimed at reaching specific goals, can be identified, compiled and compared. However, it is often found that environmental decisions are made with greater uncertainty than the other types of decisions in the society. This is mainly because of the nature of environmental parameters and their wide natural fluctuations. Another key issue, often forgotten, is that, much of the information that is available, is presented in a less understandable format. Thus, it is not only a question of inaccessible and/or incomplete information, there exists a lack of comprehensible presentation as well. Local governments in an urbanised environment are also faced with many issues and problems related to information handling. There is a constant pressure to improve services while reducing costs and to be more efficient and effective in daily operations and management activities. Even with normal growth patterns, the management of resources, facilities and operations becomes more demanding as these elements increase in number.

GIS offer a solution to many of these problems. Most of the issues and operations with which local governments are concerned relate to land or location. GIS provide the tools to manage and use the information concerning land or location related phenomena and are being extensively used in these directions. Lately, these systems are gaining widespread attention in addressing rather complex environmental problems and are also being employed to assist decision-makers for selecting from the various alternatives in development and conservation planning.

The present study attempts to illustrate a methodology to address a typical problem of identifying and ranking sites for solid waste disposal, integrating the capabilities of GIS and a systems tool which adopts the Analytic Hierarchy Process. The methodology is outlined with the example of selecting and ranking the potential disposal sites in a chosen study area, after acquiring the various types of necessary data and developing the database in a GIS environment.

2. GIS APPLICATIONS IN ENVIRONMENTAL STUDIES: STATE-OF-THE-ART

2.1 GENERAL

Information needed to address environmental problems, transcends the natural science domain, with implications in the social science domain (Committee on Global Change, 1990; Committee on Earth and Environmental Sciences, 1992). Social and technological activities throughout the world contribute to rapid and potentially stressful changes in the environment (Wheeler, 1993). Over the past few decades, there has been a rapid proliferation of pollution and waste, acid precipitation, loss of tropical forests, degradation of soils, and loss of species diversity in both plants and animals. Human activities have also contributed to increasing concentrations of greenhouse gases in the atmosphere and to stratospheric ozone depletion, which may alter the general climate. Global environmental change, thus, is an issue of international concern, especially as it affects human habitability.

2.2 SIGNIFICANCE OF APPLYING GIS IN ENVIRONMENTAL STUDIES

Providing policy analysts and researchers with information required to confront environmental problems is an important task (Cheng *et. al*, 1996). Relevant information is sometimes difficult to acquire, and once acquired, its sheer volume may make the task of managing the information difficult. Digital cartographic modelling techniques in environmental planning (Tomlin, 1983) and mathematical structures for cartographic modelling in environmental analysis (Tomlin and Berry, 1979) have been reported in literature, ever since the late 1970s. Representation and application of knowledge about the spatial processes in environmental management, has also received consider-

able attention (Davis *et al.*, 1988; Davis *et al.*, 1991). But environmental studies require the integration and simultaneous analysis of a wide spectrum of physical and human resource database, to produce useful information for the research and policy-making community. This, *integrated multi-layered analysis* approach is one of the typical features of GIS and in fact, the advocates of these systems uphold this singular feature and proclaim its efficiency to address such problems. Early attempts to develop information systems to address environmental problems were reported by the Commission on Geographical Data Sensing and Processing (Tomlinson, 1970).

2.3 ECOLOGICAL AND ENVIRONMENTAL STUDIES ON GLOBAL SCALE

The environmental modelling community is extensively using spatial database in existing GIS programmes (Wheeler, 1993). As such, even the United Nations Environmental Programme involves extensive application of GIS (Mooneyhan, 1988). Many of these models were examined at the First International Workshop on Integrating GIS and Environmental Models, held in Boulder, Colorado, 15-18 September, 1991 (Wheeler, 1993). Kineman *et al.* (1986) presented a review of the developments in global databases for the environmental sciences. Mason and Townshend (1988) reported the progress in research related to GIS, at the Natural Environment Research Council. Townshend (1991) presented the general inter-relationship between environmental databases and GIS.

Improvisations, have been made within the basic structure of GIS, to address problems defined by Earth sciences. Beller *et al.* (1991), introduced a prototype for a temporal GIS, which couples a commercial GIS package with ecological and atmospheric models. Rhind *et al.* (1986) reported the evolution of an environmental information system. Recently, Cheng *et al.* (1996) reported the development of a similar system, exclusively for environmental data analysis – ENFORMS (Environmental Information System), which is designed to support data integration activities, using the tools available in a GIS environment and environmental models.

2.4 WATER POLLUTION RELATED APPLICATIONS

In the field of environmental studies, the application of spatial data-based models for water pollution related issues is common. The most widely known example of a regional scale model for assessing vulnerability to groundwater pollution is DRASTIC (Aller, 1985): the Environmental Protection Agency's risk assessment and planning tool. Numerous efforts have also been made to address non-point source pollution. Linking of GIS, within the framework of an urban non-point source pollution model has been reported in literature (Harris *et al.*, 1991). Kim and Ventura (1993a, 1993b) and Ventura and Kim (1993) reported the results of a large-scale modelling of urban non-point source pollution in a GIS environment. Application of GIS has also been reported in the context of storm-water pollution control practices (Prey *et al.*, 1993).

Jensen *et al.* (1990) developed an index for environmental sensitivity for oil spills, using remote sensing and GIS techniques. Populus *et al.* (1995), assessed the environmental sensitivity of shorelines, to marine pollution. Their research is directed to address oil pollution problem in the Loire estuary, France, and relevant data, including remotely sensed images, and information about the coastline, sediments, vegetation, etc., were used in ranking the shoreline in terms of the environmental sensitivity.

2.5 EVALUATION OF SOLID/HAZARDOUS WASTE DISPOSAL SITES

In recent years, GIS have found applications in the field of solid waste management. Evaluation of hazardous waste sites using maps, aerial photographs and other remote sensor data have been reported (Lyon, 1987). Jensen and Christensen (1986) presented a classic case of land capability analysis of GIS by an example of solid and hazardous waste disposal site selection. Estes *et al.* (1987) reported co-ordination of hazardous waste management activities using GIS. In recent years, Pope *et al.* (1996) carried out hazardous waste site characterisation using GIS techniques. Siddiqui *et al.* (1996) and Kao and Lin (1996) have reported the application of GIS techniques for the identification of sites suitable for landfilling purposes.

2.6 PROBLEMS OF THE DEVELOPING COUNTRIES

Yeh (1991) and Perera and Tateishi (1995), discuss about the practical applicability of GIS in developing countries. Perera and Tateishi (1995) argue, that although population control is beyond the curriculum of environmental scientists, resource management is an important issue, and newly developed remote sensing techniques and GIS have a crucial role in this field. But, they also note that, the application of these technologies shows large differences in the developed and the developing countries. Perera and Tateishi (1995), list some of the common barriers to the use of GIS and remote sensing techniques, in developing countries. They argue, that on the technological side, remote sensing and GIS have problems common to the entire world, but on the application side, the problems are much more severe in the developing countries. A database, which can be updated multi-temporally, needs the application of satellite data, which is typically a high-cost task. As such, it is almost beyond the financial capabilities of the small-scale research organisations of the third world.

2.7 THE INDIAN SCENARIO

In 1987, a base for GIS in India, was proposed (Nag, 1987). Since then, GIS have found moderately wide-scale applications in various fields, such as water resource management (Sharma and Anjaneyulu, 1993), district-level planning (Ghosh *et al.*,

1993), urban growth-trend analysis (Pathan *et al.*, 1993), etc. Novaline Jaga *et al.* (1993), have applied GIS techniques for wasteland development in the Usilampatti block of Madurai district

The most extensive application of GIS, however, has been proposed recently, by the Central Pollution Control Board (CPCB) for the preparation of environmental atlases. In the 39th meeting of the Chairmen and the Member Secretaries of the Pollution Control Boards/Committees held in New Delhi during August 2-3,1994, it was felt that there was a need to prepare district-wise zoning atlases in various states for siting of industries based on environmental considerations. The details of the districts chosen, for which the work was taken up for the year 1995-96, are listed in Table 2.1. The following were the imperatives of the project: (a) to zone and classify areas in the district for siting of industries, (b) to identify locations for siting of industries, and (c) to identify industries suitable for the identified sites. The CPCB had developed draft guidelines on the preparation of the Zoning Atlases (Manual for the Preparation of Zoning Atlas for Siting of Industries, 1995).

The siting of industries has its influence on the environment. The sensitivity of an area due to pollution from industries needs to be evaluated so as to minimise the environmental impacts and risks. The CPCB identifies the major components of the sensitivity as air pollution sensitivity, water pollution sensitivity and land pollution sensitivity (Manual for the Preparation of Zoning Atlas for Siting of Industries, 1995). Each of these components have a number of factors of influence, which can be visualised by breaking up these components into sub-categories to measurable parameters or indicators. The details of these categories and the source of these data are noted in the draft guidelines (Manual for the Preparation of Zoning Atlas for Siting of Industries, 1995) and are listed in Table 2.2. The combined effect of the various factors of influence on the respective components is typically determined by the *overlay* process in a GIS environment.

The overlay process is explained by the following example: the sensitivity of the air is dependent on aerial sensitivity, dispersive sensitivity, air pollution potential of the industries and the distance from settlements. Each of these sub-categories, for a particular region, are recorded on separate maps and based on the real-world conditions, each of these sub-categories are classified as *high*, *medium* or *low*. This categorisation is based on a set of criteria formulated by the CPCB. For the evaluation of the composite effect of the different factors, the different maps of the sub-categories are superimposed on each other and the resultant condition is recorded. If the aerial sensitivity is *low* and the dispersive sensitivity is *high*, then their combined sensitivity may be *medium*. This is true in general, but the combined effect depends on the local conditions as well. Similarly, the overlays can be made to arrive at the maps showing the combined effect of the other air sensitivity factors and finally, the map showing sensitivity of the air at various places in the districts as *high*, *medium* or *low*.

Table 2.1: The Selected States (1995-96) for the Preparation of Zoning Atlases for Siting of Industries

S. NO.	STATE	EXECUTING ORGANISATION	DISTRICT
1.	Orissa	Orissa State Prevention & Control of Pollution Board	Sundargarh
2.	Uttar Pradesh	Uttar Pradesh Pollution Control Board	Ghaziabad
3.	Kerala	Kerala State Pollution Control Board	Palakkad
4.	Himachal Pradesh	Himachal Pradesh State Pollution Control Board	Solan
5.	Maharashtra	Maharashtra Pollution Control Board	Ratnagiri
6.	West Bengal	West Bengal State Council of Science & Technology	Bankura
7.	Rajasthan	Rajasthan Pollution Control Board	Udaipur
8.	Gujarat	Gujarat Pollution Control Board	Panchmahal
9.	Bihar	Bihar Pollution Control Board	Jamshedpur
10.	Assam	Assam State Pollution Control Board	Entire State
11.	Manipur	Manipur Pollution Control Board	Entire State
12.	Karnataka	Karnataka State Council for Science and Technology	Bangalore, Mysore
13.	Madhya Pradesh	Environmental Planning & Co-ordination Organisation	Chhindwara

Table 2.2: Data Requirement for the Preparation of Zoning Atlases and the Data Sources

S. No.	MAP/FEATURE	DATA SOURCES
I	**Sensitive Zones**	
1.	Reserved forests	National Remote Sensing Agency (NRSA), Hyderabad and regional centres; Ministry of Env. & Forests; State Forest Dept.; Dept. of Agriculture; Forest Research Institute
2.	National parks, Sanctuaries, Biosphere reserves	Ministry of Env. & Forests, Botanical Survey of India
3.	Coastal areas up to 500 m and estuaries (protected corals, mangroves, breeding grounds, endangered habitats)	Port Trust/Shipyard Authorities; Fisheries Dept.
4.	Monuments of national significance	Tourism Dept.; Central/State Archaeological Survey of India (ASI)
5.	Military areas	Ministry of Defence; District Collectorate

Table 2.2 continued on next page

S. No.	MAP/FEATURE	DATA SOURCES
6.	Places used for organised bathing	Public Works Dept.; District Collectorate
7.	Others (as specified by the State/District)	Town and Country Planning Organisation (TCPO); Tourism Development Corporation; District Planning Authority
8.	Monuments of State/Local significance	Tourism Dept. - Central/State; ASI; District Collectorate
9.	Socially critical areas and spots • scenic areas • beach resorts • hill resorts	Dept. of Tourism/Tourism Development Corporation; ASI; Local Govt.; Primary Surveys
10.	Tribal settlements	Dept. of Social Welfare
11.	Agricultural research stations	Dept. of Agriculture
12.	Wetlands	Wetland Development Board; Irrigation Dept.
13.	Habitats of endangered species	Zoological Survey of India (ZSI); World Wildlife Fund (WWF)
14.	Flood-prone areas/water bodies	State Flood Control Boards; Irrigation Dept.; Public Works Dept.; TCPO

II	Land Related Factors	
1.	Physiography	Central Ground Water Board (CGWB), Delhi and regional offices; State Directorate of Mining and Geology; Survey of India Topography Sheets
2.	Land capability	Soil Survey Dept.; Irrigation Dept; Statistical Handbook; Waste lands/Wet lands Development Board; Horticulture Dept.
3.	Contaminated sites • solid waste disposal sites • hazardous waste disposal sites	Central and State Pollution Control Boards; Municipal/Local Authorities
4.	Waste Lands	NRSA; National Waste Land Development Board
5.	Salt-affected areas	NRSA
6.	Real land use • built-up areas • agricultural lands • forest lands • waste lands	NRSA; National Atlas and Thematic Mapping Organisation, Calcutta; National Bureau of Soil Survey and Land Use Planning; All India Soil & Land Use Survey; District Collectorate; Local Planning/Development Authorities

Table 2.2 continued on next page

S. No.	MAP/FEATURE	DATA SOURCES
III	Water Related Factors	
1.	Surface hydrology • rivers with perennial flow • seasonal rivers and rivulets • canals • reservoirs and tanks • lakes	Central Water Commission (CWC); State Irrigation Dept.; Statistical Handbook
2.	Surface water pollution • surface water quality • river water intake points • monitoring sites • river water uses	Pollution Control Boards; CWC; Irrigation Dept.; Public Health Dept.
3.	Surface water drainage and irrigation system	Irrigation Dept; CWC; CGWB
4.	Groundwater related factors groundwater use • groundwater quality • groundwater yield • groundwater table • groundwater recharge areas • groundwater protection needs • hydrogeology • infiltration rate • land use	CGWB; State Ground Water Board; Irrigation Dept; Hydrogeological atlas of Assam, Karnataka, West Bengal, Rajasthan published by CGWB
IV	Air Related Factors	
1.	Dispersive sensitivity, sensitive zones	Indian Meteorological Dept.; Survey of India Topography Sheets; Primary Survey
2.	Urban agglomerations	Census data
3.	Highly polluted area	Pollution Control Boards
4.	Prime agricultural lands	Dept. of Agriculture; Agricultural Universities; Soil Maps; Irrigation Dept.
5.	Sources of air pollution	Pollution Control Boards; Department of Industries; District Industries Centre; Industrial Infrastructure Development Corporation

2.8 IMPEDIMENTS IN ENVIRONMENTAL APPLICATIONS OF GIS

Environmental analysis, as such, is hampered by a host of informational problems (Walsh *et al.*, 1987). Lack of data, deficiencies in the quality of data, and incompatibility of data derived from different sources, cause obvious difficulties in land management. In the commentary on carrying out environmental analysis using integrated

remote sensing and GIS techniques. Davis *et al.* (1991), highlighted some of the basic scientific issues and research needs in this direction. Two general topics, relevant to environmental data, are discussed in their study: (a) the scale dependence of geographic data and the analysis of multi-scale data in a GIS environment, and (b) data transformations and information flow during data processing. The discussion of scale dependence focused on the theory and applications of spatial autocorrelation, geostatistics, and fractals for characterising and modelling spatial variations. Wheeler (1993) points out that the modelling methods applied for simulating the real-world, are in fact, one of the foremost impediments to linking environmental models with GIS for global change research. The other two obstacles, as highlighted by Wheeler (1993), include the data source and format (including the accuracy, availability of pertinent data, scale and resolution of the acquired data and the transferability of data to systems) and the inherent limitations of the GIS functions.

2.9 SUMMARY

The review of literature, though not very exhaustive, is indicative of the growing applications of GIS in environmental systems planning at various scales, i.e., local, regional and global. The major impediments in GIS applications, particularly in the context of developing countries, is the availability of a reliable database of ground information and the cost and easy accessibility to remotely sensed (particularly satellite) data of sufficiently high spatial as well as temporal resolution. In the Indian context, application s of GIS for environmental studies are very limited, but planning and regulatory agencies are now in the process of developing the basic infrastructure and have attempted to prepare environmental atlases and develop environmental management plans.

3. OBJECTIVES AND SCOPE

It was not until the nineteenth century that public health control measures became a vital consideration to public officials, who realised that food and other solid wastes had to be collected and disposed off, in a sanitary manner, to control the vectors of disease. Today, disposal constitutes the last and one of the most significant steps in solid waste management.

In India however, the practice of open dumping is extensively practised (Report of Committee on Urban Waste, 1975). Generally, the low-lying areas and outskirts of towns and cities are used for the purpose. The open dumps are, however, a menace to the ambient environment. They become source of objectionable smoke and odours and serve as breeding grounds for flies and mosquitoes. Identification of land sites for solid waste disposal, thus becomes a critical management issue and as such the selection should be based on a number of considerations. In fact, site selection is the most important of the pre-operation steps in developing a satisfactory disposal programme (Stirrup, 1965). Skitt (1979) states that it is important to remember that in the disposal process, there are many points of *no-return*, and that the correction of faults in planning and operation of disposal sites can be very costly. The selection of a disposal site involves a multi-disciplinary approach and a broad spectrum of considerations. As such, it is a multi-criteria decision-making process and the various criteria are discussed widely in literature (Tchobanoglous *et al.*, 1977; Skitt, 1979; Crawford and Smith, 1985). In general, the following are considered as some of the salient criteria for selecting a disposal site.

1) Hydrogeologically it should be such as to present no potential threat to the groundwater quality when used for the disposal of wastes.
2) The site should be free from water, either static or running.
3) It should not be nearer than a particular minimum distance (stipulated by local governments or decision-making bodies) to any dwellings, public utility facilities

like roads, highways, etc., with the prevailing wind, preferably blowing away from these facilities.

4) The existing land use must be taken into consideration; natural wastelands are most suitable.
5) It should preferably, be in a low-lying area. "The ideal situation is a depression of some form in the ground" (Stirrup, 1965).
6) The site should have no or a very mild slope.
7) It should be so situated, as to give the minimum length of haul for refuse collection vehicles.
8) It should have all the main services readily available and good access, with fast roads nearby.

The systematic evaluation of the aspects, mentioned above, warrant handling and processing of various kinds of spatial information followed by the application of systems tool which assists in assessing the impact of the various factors most judiciously. The GIS enable, in an efficient and lucid manner, the handling and processing of spatial information, while the Analytic Hierarchy Process (AHP) provides a systematic approach for assessing and integrating the impacts of various factors, involving several levels of, dependent and independent, qualitative and quantitative information. Hence, the principal objective of the present study is to establish the step-by-step procedure followed in building a database in a GIS environment and to illustrate the application of AHP, to address a typical, rather complex problem of identifying and ranking sites for solid waste disposal.

In general, the objectives of the present study can be roundly consigned under the following heads.

1) Provide a general introduction to GIS.
2) Provide the working details for building a database in the systems environment, including the techniques for handling and modelling spatial data.
3) Illustrating the capabilities of GIS to address real-world problems of spatial nature, by applying the GIS database and AHP for the preliminary selection and ranking of sites suitable for solid waste disposal, for a particular area.

The scope of the present study is limited to preliminary selection and ranking of potential solid waste disposal sites for Kanpur city, taking into account some of the aforementioned considerations. These considerations were broadly classified into 3 groups, namely, hydrogeological/geological factors, including the groundwater table depth and the surface soil type; terrain characteristics, including the elevation above the mean sea-level (to identify low-lying areas) and the slope; and some environmental considerations, including the distance from water bodies (static and running), and public facilities like roads and rail networks.

4. GEOGRAPHICAL INFORMATION SYSTEMS: A REVIEW

4.1 HISTORICAL

In the introduction to a collection of papers on Geographical Information Systems, the editors, Peuquet and Marble observe that, "We live in a world which is basically spatial in nature. We are accustomed, on a routine basis, to dealing with the complex spatial interactions that form much of our daily lives" (Peuquet and Marble, 1990). The collection of data about the spatial distribution of significant properties of the earth has long been an important part of the activities of organised societies (Burrough, 1986). From the earliest civilisation to modern times, spatial data has been collected by navigators, geographers and surveyors and rendered into pictorial form by map makers and cartographers. One of the greatest of the modern travel writers, Paul Theroux (1985), in his essay *Mapping the World*, quotes Sir Alexander Hosie, who stated: "It would seem as though cartography were an instinct implanted in every nation with any claim to civilisation." Spatial data handling is thus, historically quite an old practice and as such, Peuquet and Marble (1990) even state that the first map is perhaps even older than the first alphabet.

With the passage of time, the demands for maps of the topography and specific themes of the earth's surface, such as natural resources, had accelerated greatly (Burrough, 1986). Especially in the twentieth century, in the decades of 1960s and 1970s, new trends emerged in the ways in which mapped data were being used for resource assessment, land evaluation and environmental planning (Tomlinson, 1972). Realisation dawned upon researchers and users that many of the different aspects of the earth's surface did not function independently, but were highly correlated. This awakened the need for an integrated and multi-disciplinary approach towards the evaluation of these aspects, and perhaps it was this realisation coupled with the rapid pervasion of the computer age, that saw the genesis of a mechanised spatial data handling system, known as *Geographical Information Systems* (GIS), which grew up to automate the manipulation and integration of spatial data.

These systems, permit the user to bring together information from varied and numerous data sets into a composite environment for either visual display or analytical modelling purposes without the laborious manual processing which characterised past map analysis efforts (Peuquet and Marble, 1990).

Today's GIS is the result of over three decades of scientific research and developments in this field, since the pioneering efforts of the Canada Geographic Information Systems (CGIS) group, under the direction of Dr. Roger F. Tomlinson, and like many other innovations, it has rapidly increased its adoption rate after many years of slow growth (Tomlinson, 1972). As far as the significance of this new technique in spatial data handling is concerned, it can be roundly summed up by Ronald Abler's statement that "GIS technology is to geographical analysis what the microscope, the telescope, and computers have been to other sciences. The analysis and processing capabilities inherent in GIS could help resolve some long-standing dilemmas in geographical analysis. They could therefore be the catalyst needed to dissolve the regional-systematic and human-physical dichotomies that have long plagued geography" (Abler, 1987).

4.2 DEFINITIONS OF GIS

While the origin of GIS have been traced to early works in computer mapping, there is a clear notion that the field is broader in scope today than simply automated map production (Ducker, 1979). The original work of the International Geographical Union Commission on Geographical Data Processing and Sensing resulted in a major two-volume document that outlined the field and provided the basis for most of the subsequent efforts (Cowen, 1988). In that compendium, Tomlinson stated that GIS "is not a field by itself but rather a common ground between information processing and the many fields utilising spatial analysis techniques" (Tomlinson, 1972).

In general, five approaches to defining GIS are found in literature. These definitions are discussed in the following sections.

4.2.1 The *Process-oriented* Approach

Process-oriented definitions, based on the idea that an information system consists of several integrated sub-systems, that help convert geographical data into useful information, were formulated in the 1970s (Calkins and Tomlinson, 1977). Logically, the entire system must include procedures for the input, storage, retrieval, analysis and output of geographical information and as such the definition of GIS as enunciated by Clarke (1986) and Burrough (1986) looks upon these systems as a computer-aided technique for the *capture, storage, retrieval, analysis* and *display* of spatial data. The value of these systems is determined by their ability to deliver timely and useful information. However, Burrough (1986) points out that GIS should be thought of as being very much more than means of coding, storing and retrieving data about aspects of the earth's surface. In a very real sense, the data in GIS, whether they are coded

from the surface of a piece of paper or from invisible marks on the surface of a magnetic tape, should be thought of as representing a model of the real-world (Bouillé, 1978). Cowen (1988) argues that although such a process-oriented definition is extremely valuable from an organisational perspective, as well as for establishing the notion that the systems are dynamic and should be viewed as a commitment to long-term operation, the definition is far too inclusive to help distinguish GIS from computer-aided cartography, location-allocation exercises or even statistical analysis. Poiker (1985) points out that any form of process-oriented definition of GIS emphasises the end use of the information and, in fact, need not imply that automation is involved at all in the processing.

4.2.2 The *Application* Approach

A slight modification of the process-oriented approach yields a definition which categorises GIS according to the type of data being handled. Pavlidis' classification scheme (Palvidis, 1982) includes natural resource inventory systems, urban systems, planning and evaluation systems, and management command and control systems. An area of greatly increased attention, is the field of land records or multi-purpose cadastre systems, that use the individual parcels as basic building blocks (McLaughlin, 1984). Cowen (1988) points out that defining GIS on the basis of applications may help to illustrate the scope of the field, but it does not enable one to distinguish GIS from other forms of automated data processing and concludes that GIS are independent of both scale and subject matter.

4.2.3 The *Toolbox* Approach

The toolbox definition of GIS derives from the idea that such a system incorporates a set of sophisticated computer-based procedures and algorithms for handling of spatial data. Published works by Tomlinson and Boyle (1981) and Dangermond (1983) provide a complete delineation of the operational software functions that one should find in a full-featured GIS. Typically, these tools are organised according to the needs of each process-oriented sub-system (e.g., input, analysis or output). The toolbox definition implies that all of these functions must be present and should work together efficiently to enhance the transfer of a variety of different types of geographical data through the system and ultimately into the hands of the end user. With reference to this particular perspective of definition, Cowen (1988) comments that thus, despite being important components of automated geography, neither digitising, image processing, nor automated mapping systems qualify as GIS, as they do not possess all the necessary tools and do not provide the overall integration of functions.

4.2.4 The *Database* Approach

The database approach, refines the toolbox definition of GIS by stressing the ease of the interaction of the other tools with the database. Goodchild states that, "GIS are best defined as systems which use a spatial database to provide answers to queries of a geographical nature. The generic GIS thus, can be viewed as a number of specialised spatial routines laid over a standard relational database management system"

(Goodchild, 1985). Peuquet (1984) states that GIS must start with an appropriate data model and that the success of these systems is to be determined by the efficiency that the data model provides for the retrieval, analysis and display of the information. Some of the most important researches in GIS are now concentrating on the design of optimal database management systems to link the geographical co-ordinate information with the attributes or variables associated with the geographical entities being represented in the system (Cowen, 1988).

4.2.5 The *Decision-support* Approach

GIS have sometimes been called decision-support systems (Cowen, 1988). Calkins and others stress that the first stage of any assessment of user needs, must involve an identification of the decision-makers, an analysis of the objectives of the system, and an outline of the organisation's decision-making system (Calkins and Tomlinson, 1977). Burrough (1986) argues that since data can be accessed, transformed and manipulated interactively in a GIS environment, they can serve as a test bed for studying environmental processes or for analysing the results of trends, or of anticipating the possible results of planning decisions – "...by using the GIS in a similar way that a trainee pilot uses a flight simulator, it is, in principle, possible for planners and decision-makers to explore a range of possible scenarios and to obtain an idea of the consequences of a course of action before the mistakes have been irrevocably made in the landscape itself" (Burrough, 1986). Cowen states that GIS is best defined as a decision-support system involving the integration of spatially referenced data in a problem-solving environment, with an emphasis on the word *integration* and concludes that "GIS provides the tools, that we have always needed to truly synthesise disparate sources of spatial information"(Cowen, 1988).

4.3 COMPONENTS OF GIS

GIS essentially consists of two important components - the computer hardware and a set of application software modules.

4.3.1 GIS Hardware Modules

The general hardware components of a GIS are presented in Figure 4.1. The computer or the central processing unit (CPU) is linked to a disc drive storage unit, which provides space for storing data and program. A digitiser or other device is used to convert data from maps and documents into digital form and send them to the computer. A plotter or other kind of display device is used to present the results of the data processing, and a tape drive is used for storing data or programs on magnetic tape, or for communicating with other system. Inter-computer communication can also take place via a networking system over special data line, or over telephone lines using a device known as modem. The user controls the computer and the peripheral (a general term for plotter, printer, digitiser, and other apparatus linked to the computer) via a visual display unit (VDU), otherwise known as a *terminal*.

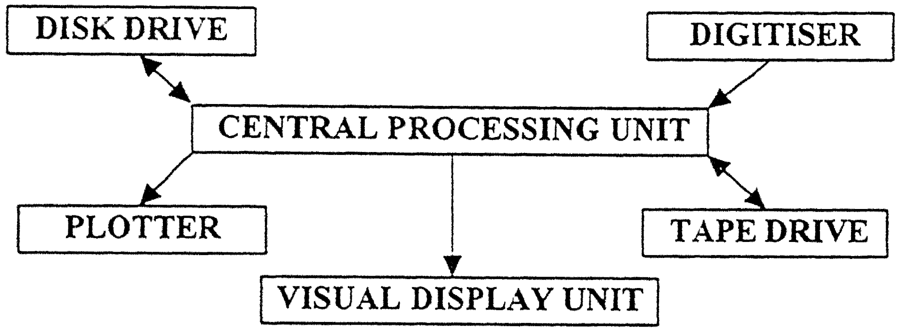

Figure 4.1: GIS Hardware Modules

The user's terminal might itself be a microcomputer, or it might incorporate special hardware to allow maps to be displayed quickly.

4.3.2 GIS Software Modules

The software package for GIS consists of five basic technical module (Figure 4.2). These basic modules are sub-systems for:

(a) data input and verification;
(b) data storage and database management;
(c) data output and presentation;
(d) data transformation;
(e) interaction with the user.

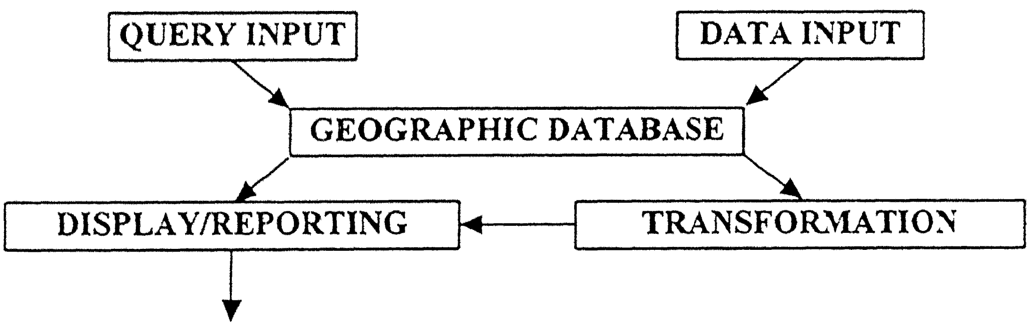

Figure 4.2: GIS Software Modules

Data input (Figure 4.3) covers all aspects of transforming data, captured in the form of existing maps, field observations, and sensors (including aerial photography, satellites, and recording instruments), into a compatible digital form. A wide range of computer tools are available for this purpose, including the interactive terminal or VDU, the digitiser, lists of data in the text files, scanners (in satellites or aeroplanes for direct recording of data or for converting maps and photographic images) and the devices necessary for recording data already written on magnetic media such as tapes, drums and disks.

Data storage and data store management (Figure 4.4) concerns the way in which the data about the position, linkages (topology), and attributes of geographical elements

(points, lines, and areas representing objects on the earth's surface) are structured and organised, both with respect to the way they are handled in the computer and how they

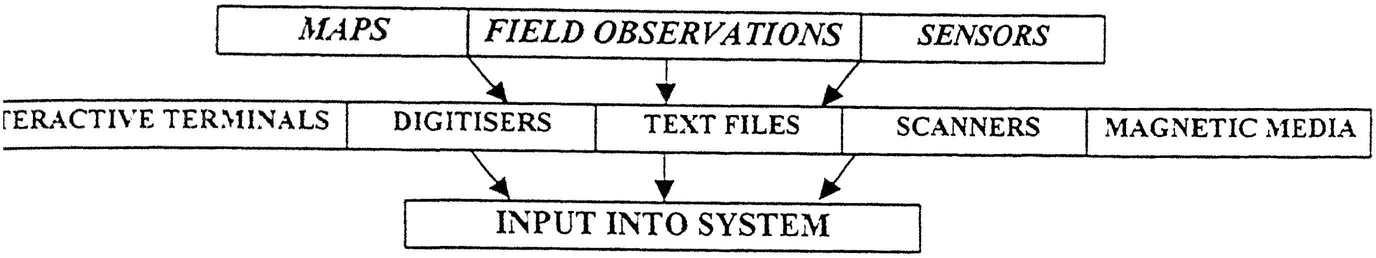

Figure 4.3: GIS Software Module for Data Input

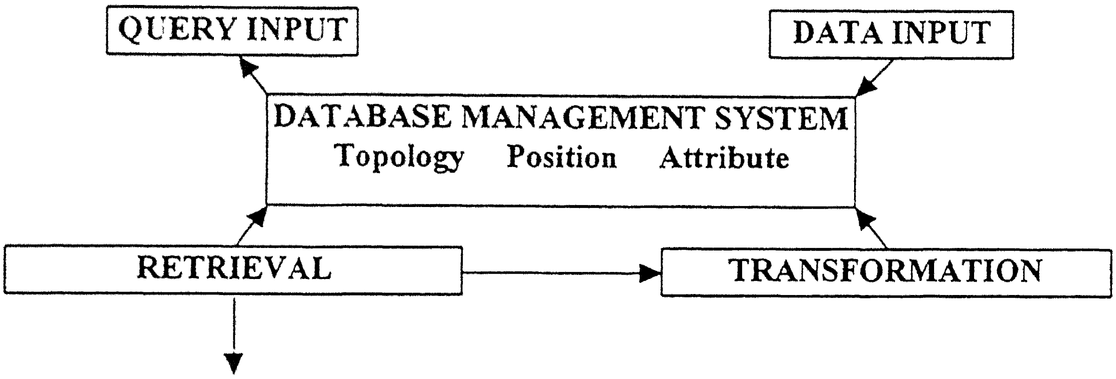

Figure 4.4: GIS Software Module for Data Storage and Management

are perceived by the users of the system. The computer programme used to organise the database is known as Database Management System (DBMS).

Data output and presentation (Figure 4.5) deal with the ways in which the data are displayed and the results of analyses are reported to the users. Data may be presented as maps, tables and figures (graphs and charts) in a variety of ways, ranging from the ephemeral image on a cathode ray tube (CRT), through hardcopy output, drawn on a printer or plotter, to information recorded on magnetic media in digital form.

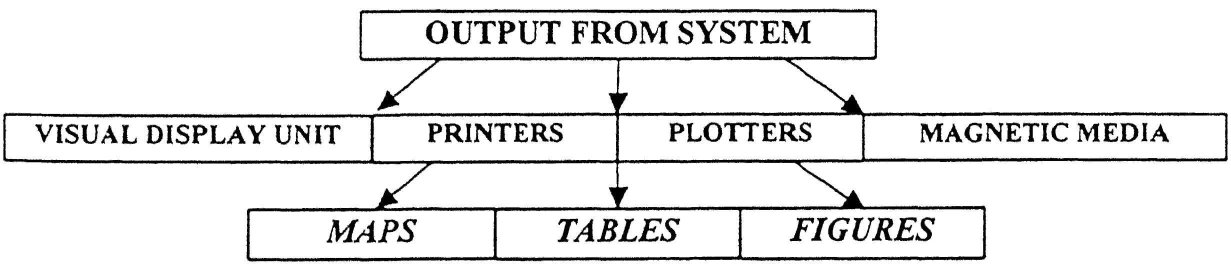

Figure 4.5: GIS Software Module for Data Output and Reporting

Data transformation (Figure 4.6) embraces two classes of operation, namely (a) transformation needed to remove errors from the data or to bring them up to date or to match them to other data sets, and (b) the large array of analysis methods, that can be applied to the data in order to achieve answers to the questions asked in a GIS envi-

ronment. Transformation can operate on the spatial and the non-spatial aspects of the data, either separately or in combination. Many of these transformations, such as those associated with scale-changing, fitting data to new projections, logical retrieval of data,

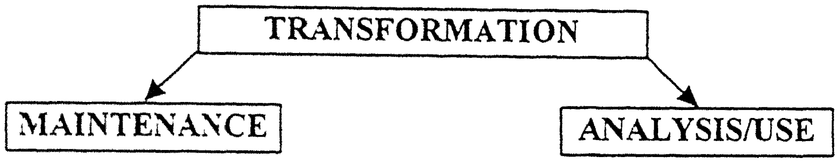

Figure 4.6: GIS software Module for Data Transformation

and calculation of areas and perimeters, are of such a general nature, that it is expected to be found in every kind of GIS, in one form or another. Other kinds of manipulation may be extremely application-specific, and their incorporation into a particular GIS may be only to satisfy the particular users of that system.

The last module in the list of the GIS software modules mentioned above, that for interaction with the user, is absolutely essential for the acceptance and use of any information system. Burrough (1986) feels that it is an aspect, that until recently has received less attention than it deserves - "...it is only in the last few years that the average user has been able to make direct contact with the computer other than via the impersonal and unforgiving media of punched paper tapes and cards handed into the computing centre. The widespread use of the personal computer and of programs that are operated by commands chosen from a menu (a list), or that are initiated by a response to requests in an English-like command language of verbs, nouns and modifiers has broken down the barriers that once frightened many a would-be computer user away for life" (Burrough, 1986). Some of the commonly asked questions are enlisted in the next section.

4.4 QUESTIONS ASKED IN GIS ENVIRONMENT

The robustness of any field of technology is evaluated, not only by the depth to which it addresses a problem, but also, by the variety of problems it can attempt to find a solution for and the variety of users it can satisfy.

Over the past few years, GIS have had a wide variety of applications (which are discussed in details in Section 4.8). As such, the designers of these systems should thus expect that the variety of users will want to ask, an almost unlimited number of questions, that will be required to be answered by certain combinations of data retrieval and transformation options. Although the range of actual questions will be unlimited, there are several broad types of questions that need to be catered for. Burrough (1986), enlists some of the general ones, covering the quest of a wide variety of users, including designers, planners, technologists and decision-makers as follows:

1) Where is object A?
2) Where is A in relation to place B?

3) How many occurrences of type A are there within distance D of B?
4) What is the function value of Z at position X?
5) How large is B (area, perimeter, count of inclusions, etc.)?
6) What is the result of intersecting various kinds of spatial data?
7) What is the path of least cost, resistance, or distance along the ground from X to Y along pathway P?
8) What is at points X1, X2,...?
9) What objects are next to objects having certain combination of attributes?
10) Reclassify objects having certain combination of attributes.
11) Using the digital database as a model of the real-world, simulate the effect of process P over time T for a given scenario S.

Many of these questions are difficult to answer using conventional methods (for example, calculating the proportion of different kinds of soil mapped requires extensive work with a planimeter) and some are still difficult and time-consuming using other computer-assisted methods. However, one of the most significant problems when using a powerful information system arises when the user unwittingly creates or propagates errors that render the work valueless (this aspect has been discussed in details in Section 4.6).

4.5 DATA STRUCTURES IN GIS

Unlike many other kinds of data handled routinely by modern information systems, geographical data are complicated by the fact that they must include information about position, possible topological connections, and attributes of the object recorded. The topological and spatial aspects of geographical data processing, distinguish systems designed for graphics and mapping from the other modern data processing systems. There are two fundamental ways of representing topological data namely, vector representation and raster representation. The vector format is characterised by three main geometric entities (primitives): points, lines and polygons, and assumes that all geographical features can be represented by a combination of these three entities. The raster format is characterised by cells (grids) located by co-ordinates, and each cell is independently addressed with the value of an attribute. In this section the characteristics of these data structures are discussed in details, with a brief overview of the historical background of these formats of representation.

4.5.1 Historical Background

The vector method for representing spatial phenomenon has, throughout history, been the most common (Maffini, 1987). The development of cartography was based on the use of lines, or *vectors*, to represent entities such as roads and streams, and to define edges between different spatial features such as land and water. Surveying and mapmaking techniques were founded on the principles of geometry and trigonometry

which employ vectors. Maffini (1987) states that, we were, perhaps from the beginning, implicitly aware that such lines often imposed on the landscape a structure which were subjective and inexact. The introduction of aerial photography to map-making made it apparent that much of the real-world is not made up of distinct lines, but nevertheless, the practice of making maps with vectors was continued. Complex optical/mechanical stereo-plotters were eventually constructed to assist human interpreters in defining sharp lines and edges in essentially continuous photographic images.

With the advent of computers, the raster data structure began to emerge as an efficient alternative for certain types of mapping. Because of the small memory and computational limitations of early computers, the raster maps produced tended to be quite coarse in comparison to conventional manually prepared (i.e., vector structured) maps. They were often perceived to be inherently inferior. However, it quickly became apparent that, while the spatial resolution of the raster approach was too coarse for some cartographic purposes, it presented some very powerful advantages in data encoding and applications which required thematic mapping and analysis. Performing multiple map overlays, for example, could be accomplished in the fraction of the time required by the vector approach.

In recent years new methods of capturing information directly with electronic sensors and raster scanners have contributed to an expanded use of the raster method. Image processing and remote sensing have created a vast pool of information which is difficult to incorporate in the vector world. The proliferation of raster-based satellite remote sensing systems, having increasing resolution, has established a very large community of experienced raster data users.

4.5.2 Vector Data Format

The vector representation of an object, is an attempt to represent the object as exactly as possible. The co-ordinate space is assumed to be continuous, allowing all positions, lengths and dimensions to be defined precisely. In fact, this is not exactly possible because of the limitation of the length of a computer character, on the exact representation of the co-ordinate of a point and because all vector display devices have a basic step size, albeit very much smaller than the resolution of most raster devices. Besides the assumption of mathematically exact co-ordinates, vector methods of data storage use implicit relation that allows complex data to be stored in a minimum of space. The most fundamental assumption of the vector format of data storage is that all geographical data can be reduced to three basic geometric primitives - the point, the line and the polygon, and that every geographical phenomenon can, in principle, be represented by one or a combination of these entities.

Point entities can be considered to embrace all geographical and graphical entities that are positioned by a single X,Y co-ordinate pair. Besides the location, other data must be stored to indicate what kind of *point* it is, and other information associated with it (e.g., groundwater depth at a particular drill site, rainfall measured at a particular gauging station, etc.).

Line entities can be defined as all linear features built up of straight line segments made up of two or more co-ordinate pairs plus an associated *code* representing the type of the line (e.g., isolines, political boundaries, etc.). The simplest line requires the storage of a *starting point* and an *end point* apart from the code. An *arc*, a *chain* or a *string* is a set of n X,Y co-ordinate pairs describing a continuous complex line. The shorter the line segments and the larger the number of co-ordinate X,Y pairs, the closer the chain will approximate a complex *curve*. Vector data formats provide efficient encoding of spatial adjacency relationship (topology). With the information of the nodes in a series of linear features, the topology of a network can be fully defined.

Polygon entities are made up of a series of closed linear features. Because most kinds of thematic mapping have to deal with polygons, the ways in which these entities can be represented and manipulated has received considerable attention (e.g., Poiker and Chrisman, 1975; Weber, 1978; Burrough, 1980). The aim of the polygon data structure is to be able to describe the topological properties of areas (i.e., their shapes, neighbours and hierarchy) in such a way that the associated properties of these spatial building blocks can be displayed and manipulated as thematic map data. Each component polygon on a map has a unique identification - shape, perimeter and area, and the neighbourhood information is encoded.

4.5.3 Raster Data Format

The simplest raster data structure consist of an array of grid cells (picture elements or *pixels*). Each grid cell is referenced by a row and column number and it contains a number representing the type or value of the attribute being mapped. In raster structure, a point is represented by a single grid cell, a line by a number of neighbouring cells strung out in a given direction and an area by an agglomeration of neighbouring cells. This type of data structure is easy to handle in the computer, particularly with high-level programming languages, because of the ease with which arrays of rows and columns can be stored, manipulated and displayed. This data structure also means that the two-dimensional surface upon which the geographical data are represented is not continuous, but quantised, which can have a significant effect on the estimation of lengths and areas, when grid cell sizes are large with respect to the features being represented. Because of the discrepancies that can arise in this way with the loss of precision associated with the cell size, many fields such as digital image processing assume that the quantised surface can be treated as continuous, so that the mathematical functions having derivatives that exist can be used (Castleman, 1979).

Raster representation assumes that the geographical surface can be treated as though it were a flat Cartesian surface. Each grid cell is by implication, associated with a square parcel of land. The resolution or the scale of the raster map is the relation between the cell size in the database and the size of the square parcel in the real-world.

Because each cell in a two-dimensional array can only hold one number, different geographical attributes must be represented by separate sets of Cartesian arrays, known as *overlays*. In its simplest form, the overlay concept is realised in raster data structures by stacking two-dimensional arrays, which results in a three-dimensional structure. The overlay concept is essentially equivalent to the *picture function* in digi-

tal image processing (Duda and Hart, 1973), a *data plane* in remote sensing (Tom *et al.* 1978) or *image-based* storage (O'Callaghan and Graetz, 1981), and it is fundamental to most raster image processing.

4.5.4 Vector versus Raster

The vector and raster methods for spatial data structuring, are distinctly different approaches to modelling geographical information. Maffini (1987), illuminates the intrinsic difference between these data structures by drawing an analogy to the wave-particle duality, of the nature of light. He states that "for understanding diffraction, the behaviour of light can best be explained by treating it as a continuous wave. The photoelectric effect on the other hand, can best be explained by treating light as parcels of photon. In physics, each of these models has validity, depending on the intended application. Similarly, the vector and raster models for representing spatial phenomenon both have merit and utility, depending on what it is we need to accomplish" (Maffini, 1987).

The relative merits and demerits of these formats are one of the most widely discussed subjects in GIS literature (e.g., Maffini, 1987; Richards, 1994). Burrough (1986) enlists the advantages and disadvantages of the two formats as reported in Table 4.1.

Evidently, both the alternate formats have their respective strengths and weaknesses for describing conditions in the real-world and Maffini (1987) argues, that in view of the technological developments, it seems unlikely that any one data structure will become dominant and that either will prevail to enjoy a place in GIS for many more years. In fact, he concludes his commentary on raster and vector formats (Maffini, 1987) on an optimistic note and states: "During the next few years more elegant and efficient ways of integrating data formatted in these two different ways will be developed. Hopefully, this information process will be intelligent and transparent to the user. In addition, some of the emerging hierarchical structures may also provide clues to the evolution of an integrated model which does not require the time consuming and error-prone translation of data from vector to raster and raster to vector."

4.6 ERRORS IN GIS PRODUCTS

Two sources of errors, namely *inherent* and *operational*, contribute to the reduction in accuracy of the products that are generated by the information systems. Inherent errors are the errors present in the source documents. Operational errors are produced through the data capture and manipulation functions of GIS.

Vitek *et al.*(1984) discuss about the occurrence of inherent and operational errors in GIS. They provide examples of inherent errors and stress the need for developing error statements for data contained within GIS. They also provide examples of operational errors present in simple products and pose the question *"can we account for the error at various stages in the development of the final GIS produet?"*. They note, that every map will contain inherent errors, based upon the nature of the source map pro-

jection, map construction techniques and symbolisation of data. The integration of data, from different sources and in different original formats (e.g., points, lines and areas), at different original scales and possessing inherent errors, will yield a product of

Table 4.1: Advantages and Disadvantages of Vector and Raster Methods (Burrough, 1986)

VECTOR METHODS
Advantages (i) Accurate graphics (ii) Compact data structure (iii) Good representation of phenomenological data structure (iv) Topology can be completely described with network linkages (v) Retrieval, updating and generalisation of graphics and attributes are possible ***Disadvantages*** (i) Complex data structures (ii) Combination of several vector polygon maps or polygon and raster maps through overlays creates difficulties (iii) Simulation is difficult because each unit has a different topological form (iv) Spatial analysis and filtering within polygons are impossible (v) Display and plotting can be expensive, particularly for colour and cross hatching (vi) The technology is expensive, particularly for the more sophisticated software and hardware
RASTER METHODS
Advantages (i) Simple data structure (ii) Various kinds of spatial analyses are easy (iii) Simulation is easy because each spatial unit has the same shape and size (iv) The overlay and combination of mapped data with remotely sensed data is easy (v) The technology is cheap and is being energetically developed ***Disadvantages*** (i) Large volumes of graphic data (ii) Network linkages are difficult to establish (iii) The use of large cells to reduce data volumes means that phenomenologically re- cognisable structures can be lost and there can be a serious loss of information (iv) Crude raster maps are considerably less beautiful than maps drawn with fine lines (v) Projection transformation are time consuming unless special algorithms or hard ware are used

questionable accuracy. They also note that operational error is introduced during data entry, data manipulation, data extraction and data comparison within the GIS, and

conclude that such errors may result in an error-filled products which may fail to impart the information intended or, even worse, mislead the user (Robinson and Jackson, 1985; Burrough, 1986).

Marble and Peuquet (1983), report that the accuracy of a GIS-derived product, is dependent on characteristics inherent in the source products and on user requirements, such as scale of the desired output product and method and resolution of data encoding (vector or raster). Newcomer and Szajgin (1984) argue that the highest accuracy of any GIS output product, can only be as accurate as the least accurate data plane of information involved in the analysis. The final product, they note, will be less accurate than any of the individual layers utilised.

Burrough (1986) states that results from some mathematical models in GIS may have such error margins, as to be useless for specific applications requiring the most stringent levels of accuracy. Manipulation of thematic overlays, within the GIS, to derive model variables, are susceptible to inherent and operational errors. According to Mead (1982), the quality of data within the GIS is affected by the age of data, areal coverage, source map scale, source map resolution, format, accessibility of data, costs of data acquisition, degree of modification from the source data and data accuracy. Stanilawski *et al.*(1996), estimated the absolute and relative positional accuracy of data layers in GIS through error propagation.

4.7 RELATIONSHIP OF GIS WITH OTHER FIELDS OF TECHNOLOGY

The development of GIS has both drawn upon and contributed to a number of other technical areas. The main conceptual development of these systems has come, of course, from geography and cartography, but their present effective status would not have been possible without a number of significant, interdisciplinary interactions.

4.7.1 Computer Graphics/Image Processing

The output (or reporting) stage of GIS is heavily dependent upon the availability of rapid, high resolution, graphics displays. These displays have also been of significant utility in a substantial number of other fields. This high demand level has led to the rapid development of low-cost, sophisticated computer graphics systems which are now capable of reproducing any desired spatial data display.

Computer graphics, and especially image processing, has contributed far more than cost-effective and sophisticated hardware (Marble, 1984). Many of the algorithms used in computer graphics and the data structures used in image processing have proven quite useful in spatial data handling.

Marble(1984) states that conversely, a number of developments pertaining to algorithms and data structures for spatial data handling have proven to be of considerable utility in the computer graphics area.

4.7.2 Computational Geometry

A specialised area of computer science, deals with the analysis of algorithms for handling geometric entities. The work that has been done in this field has led to significant improvements in the field of GIS (e.g., the development of the ARC/INFO system by ESRI, Inc.) and has stimulated a growing interest in the explicit analysis of the efficiency of algorithms used in spatial data handling systems (ESRI, 1990).

4.7.3 Database Management Systems

In contrast to computational geometry, theoretical and practical work on systems for managing large volumes of data has occupied the attention of a substantial number of academic and commercial researchers in computer science. Although a number of these systems have been applied to simple forms of spatial data (e.g., point data), their developmental emphasis on one-dimensional data has limited their utility for general spatial data handling. Current approaches tend to make use of a general DBMS for handling the spatial attribute information and specialised software for storage, retrieval and manipulation of the spatial data. Marble(1984) feels that the inability of existing DBMS to efficiently handle large volumes of spatial data represents a real obstacle in the development of global databases.

4.7.4 Software Engineering

Within the last few decades, increasing attention has been given within computer science to the problems of efficient design of large software systems. This work has become known as software engineering and, through the concept of the system life-cycle, has led to the development of conceptual models and tools for effective system design. Attention has been given, in the field of GIS, to the problems of system design and selection and it is interesting to note that many of the notions contained in these early design models, are parallel to some of the concepts found in modern software engineering practice (e.g., structured functional requirements analysis).

4.7.5 Remote Sensing/Photogrammetry and Cartography

The great majority of the data contained in digital spatial databases is derived from remote sensing. The derivation from photogrammetry is indirect, since most data are captured by digitisation (either manual or automatic) from map documents which are, in turn, frequently derived from photogrammetric processing of aerial photography. However, as far as remote sensing inputs are concerned, especially those based on orbital sensors, direct utilisation is extensively popular. Considerable emphasis is placed on data acquisition and data analysis in remote sensing. Within remote sensing

however, consideration must be given to the destination of the data gathered, which may either be used as input to a GIS or be represented in a graphic form. Furthermore, the computer systems used in modern digital image analysis have much in common with GIS processing. As such, many vendors have, without changing the data structures, implemented GIS functions in their image processing systems and vice-versa (e.g., the ILWIS package).

The analysis of geographical information to support decisions, which is the main concern of practitioners of GIS, is dependent on the way in which data is gathered. When data is derived from remote sensing, quality and organisation are dependent on the methodology in that field. Similarly, while GIS professionals are not primarily concerned with the quality of the graphics that may be derived from the information, they must be cognisant of the implications of the data manipulations, upon the message presented in the resultant map.

The cartographer may map information which is a direct product of remote sensing or which have been processed by a GIS. The relationship of remote sensing and GIS with cartography, thus, is like the traditional view of data acquisition and data manipulation, as the precursor of the map. However, remote sensing and GIS have a body of knowledge and require such a level of expertise that it is no longer realistic to envisage a cartographer as being an expert in these areas as well.

4.8 APPLICATIONS OF GIS

The history of using computers for mapping and spatial analysis shows that there has been parallel developments in automated data capture, data analysis and presentation in several broadly related fields (Burrough, 1986). It is essentially in these fields, that GIS have found wide applications and are beginning to yield practical benefits. The summarised list of some of these fields, as enlisted by Dangermond (1983) is as follows:

1) Engineering mapping.
2) Automated photogrammetry.
3) Sub-division design (cut/fill, street layout, parcel layout).
4) Cadastral mapping.
5) Highway mapping.
6) Utility facility mapping and management.
7) Geodetic mapping.
8) Event mapping (accidents, crime, fire, facility breakage, etc.).
9) Census and related statistical mapping.
10) Management of well log data.
11) Land use planning and management.
12) Environmental impact studies.

13) Natural resource mapping and management (also included would be forest management, agricultural management, ecological and biological studies).

4.9 AN EXAMPLE OF GIS – ILWIS

For the present study, the ILWIS (Integrated Land and Water Information System) package was used. It is a raster-based practical geoinformatics and remote sensing system, which provides the key to wealth of information, for various applications, including urban analysis, land evaluation, environmental management, hazard monitoring, rural development and watershed management. It is a system that integrates image processing and spatial analysis capabilities, tabular databases and conventional characteristics. Data acquisition from aerospace images, forms an integral part of the system, enabling effective monitoring of environmental parameters. This feature is important for regions where data are scarce or difficult to gather. The design of the system takes into account, that not all GIS users have a thorough knowledge of computers. All operations are therefore, performed through a user-friendly menu, which allows the user to concentrate on application, rather than learning the intricacies of the system. Experienced users can, on the other hand, perform operations directly through commands and/or command files. The characteristic features of the major software modules of ILWIS are discussed in the following sections.

4.9.1 Data Input and Output

Conversion programmes allow the import and export of remotely sensed data, tabular data, raster maps and vector files from or to several other formats. Analogue data can be transformed into vector format by means of user-friendly digitising programme or by the *on-screen* digitising (digitising with any raster map or image as a screen underlay), which is one of the most important features of ILWIS.

The system supports black and white and colour hardcopy output devices, in either vector or raster format. It supports standard pen-plotters, black & white and colour matrix printers and laser printers. Conversion routines from ILWIS data formats to number of other data formats (raster, vector and tabular) are available.

4.9.2 Spatial Modelling

Complex modelling procedures can easily be executed by the *map calculator*. The map calculator includes an easy-to-use modelling language and enables the use of mathematical functions and expressions. Complex procedures can be executed rapidly on the portions of a test area and after evaluation and assessment of the results, the procedure can be applied to the entire study area. Tabular and spatial databases can be used, both independently, and on an integrated basis. Calculations and simple statistical analysis can be done by the *table calculator*. Computational procedures are improved by the appropriate use of modelling processes. Not all analyses involves the use of spatial databases, whenever possible, knowledge-driven queries in the tabular

database, should take precedence over similar operations in the spatial databases. Fast overlay procedures constitute one of the major characteristics of the system.

4.9.3 Image Processing

Image processing capabilities integrated with spatial modelling and tabular databases constitute a powerful tool. Together they enable analysis of data, which only recently been possible. ILWIS also incorporates conventional image processing capabilities such as filtering, geometric corrections and classification procedures.

4.9.4 Special Features

For the interpolation of point data and contour lines, special programmes are available to create Digital Elevation Models. Special filters and functions are available to produce slope and aspect maps. Functions and filters can also be defined by the user.

5. DATA ACQUISITION AND THE DEVELOPMENT OF THE DATABASE

5.1 GENERAL

The transfer of data from analogue documents to digital form, represents one of the time-consuming and costly steps in creating an operational GIS. Much of this encoding activity typically involves a human operator, who is interacting with instrumentation (e.g. a digitiser), that transforms two-dimensional or sometimes three-dimensional data, stored on paper, into precise digital co-ordinates. In some cases, which are limited by the quality and complexity of the documents available, automatic or scan digitising may be used to create the digital file. The speed of encoding is substantially increased through the use of scan digitising, but the cost of scan digitising instrumentation, which is capable of retaining cartographic accuracy, is significantly greater than in manual digitising systems. The goal of this encoding process is to create *clean* and useable digital files.

Both manual and scan digitising must be followed by edit operations, which check the digital data against the original document, and correct the measurement errors induced by the hardware and software and in the case of manual digitisation, the human operator. The edit process requires substantial human interaction, but is largely facilitated by the in-built data transformation module (as described in Section 4.3.2). Failure to edit the newly digitised data, is very likely to cause substantial downstream errors in GIS operations. Therefore, not only is the appropriate hardware and software needed, but a standardised set of operator procedures for the entire process is essential in order to ensure generation of data of consistent quality. This need to structure the data-capture process, holds for scan digitising as well as for vector digitising.

There are six basic kinds of systems which provide the digital information that are appropriate for integration into GIS. First, computer aided drafting systems which capture and maintain maps as electronic drawings. These systems range anywhere from

for capturing information and spatial features in vector format, such as those based on digitising, scanning and photogrammetry. Third, image-processing and other raster-based operating systems which capture information in raster format. Fourth tabular DBMS and their related files. Fifth, word processing systems for managing text. Sixth, video and laser image systems which capture and manage pictures. Systems of the second and the third kind have been used for the present study.

5.2 DESCRIPTION OF THE STUDY AREA

Kanpur Nagar district of Uttar Pradesh, India, lies approximately between 26°10' and 26°38' North latitudes, and between 80°7' and 80°36' East longitudes. It covers an area of 1040 square kilometres, with population of 2,493,201 persons (population density ≅2397 persons per square kilometre). The district is mainly inhabited by urban population (85%). City of Kanpur where 1.96 million people live, ranks 9th by population size of all cities in India. It had a decadal growth rate of 31.49 percent during 1981-91.

The district was created in 1981 comprising one *tahsil*, three development blocks, one municipal corporation, one cantonment, one town area *samitee*, thirty six police stations and 261 villages. The district has an ancient past and a rich cultural heritage.

Physiographically, the district is the Eastern part of the Ganga-Yamuna *doab* having very gentle to gentle slopes from north-west to south-east. The Ganga and the Rind are the main rivers. The district can be divided into two physiographic regions, viz. (1) Ganga-Pandu tract, and (2) Pandu-Rind tract.

Geologically, the area is underlained by unconsolidated sediments of quaternary to recent age. The younger alluvial, older alluvial and saline and alkaline soils are found in the district.

The district experiences very hot summer and very cold winter with mean maximum temperature of 45.6°C and mean minimum temperature of 4.7°C. The average annual rainfall is 879 mm.

The district has 17,966 ham net utilisable recharge and 6,582 ham. net draft of groundwater.

In the district, the area under cultivation is 60,085 hectares (ha.), followed by other uses of land (15,151 ha.), fallow (10,966 ha.), culturable waste (5,718 ha.), unculturable waste (5,577 ha.) and forest (4,954 ha.). The major crops grown are wheat (40%), rice (9%), *jowar* (7%), horse-gram (6%), barley, mustard and maize (4% each), accounting for 84% area to the total gross-cropped area.

The working force (662,443 workers) is dominated by other activities that indicates the urban dominance, followed by agricultural activities (15.2%) and household industry (5.8%).The district consists of 662 factories with 67,623 workers and 4,501 units

of small-scale industries with 34,956 workers. Most of the industries are concentrated in and around the city of Kanpur.

The Howrah-Delhi main railway, Bombay-Lucknow main railway and the national highways Nos. 2 and 25 pass through the district.

The district is having amenities and facilities of 165 post offices, 17 telegraph offices, 25,757 telephones, 1231 basic schools (the literacy rate is around 58.8%), 25 degree colleges, 2 universities, industrial institute, polytechnic, the Indian Institute of Sugar Technology, the Indian Pulses Research Institute and the Indian Institute of Technology. Medical facilities are provided to the population through 93 allopathic, 29 *ayurvedic*, 26 homeopathic dispensaries/hospitals, 7 leprosy, 1 tuberculosis and 1 isolation hospital.

The present study was carried out on a part of the Kanpur Nagar district, primarily because of the convenience of data collection. The study area covers the entire Kanpur city and is defined by the rectangle bounded by the latitudes 26°22'30"N & 26°32'30"N and the longitudes 80°12'30"E & 80°25'00"E. The exact location of the study area with respect to the Kanpur Nagar district is shown in Figure 5.1.

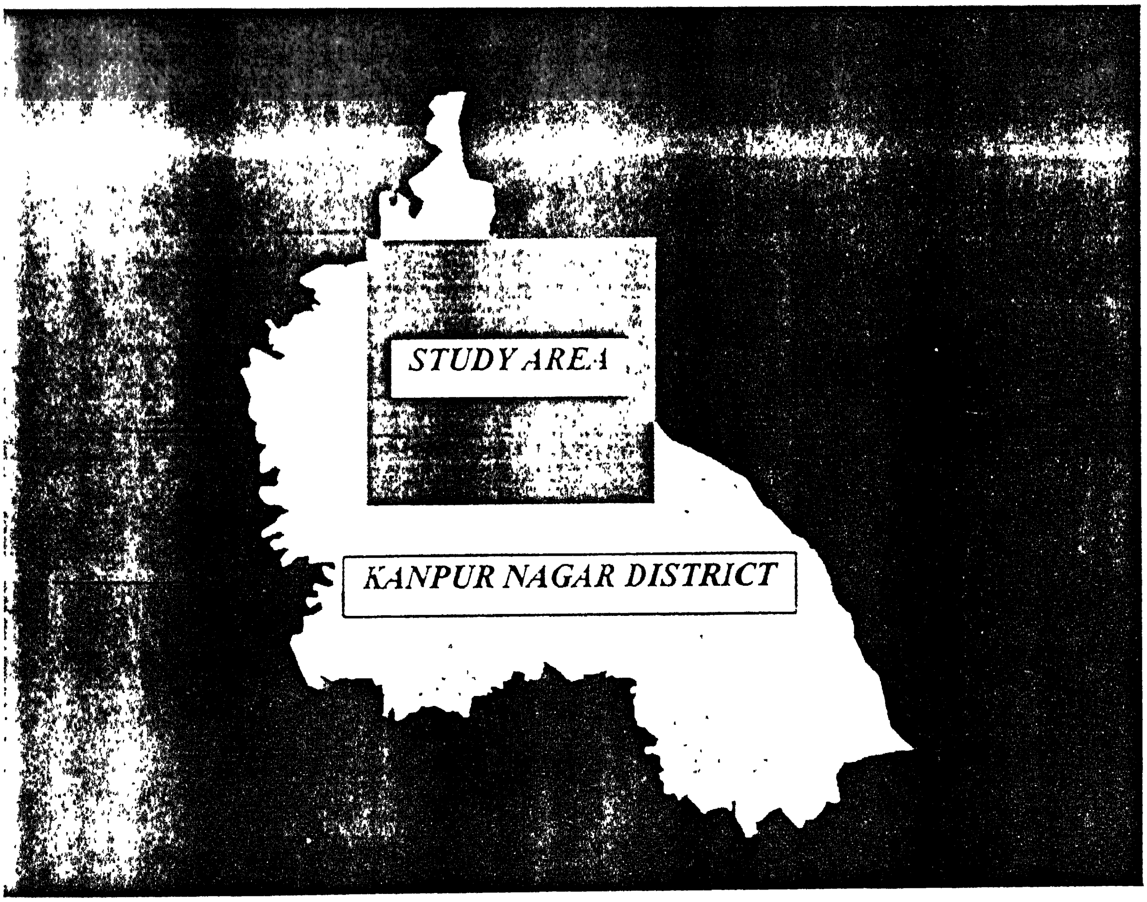

Figure 5.1: Kanpur Nagar District and the Study Area

The area falls in the Ganga-Pandu tract, and covers around 383.336 square kilometres also including parts of the neighbouring districts, viz., Unnao and Kanpur Dehat. The Kanpur Nagar district however, covers the majority of the study area (85.29%) with

about 327 square kilometres, followed by about 55 square kilometres of the Unnao district and about 1 square kilometre of Kanpur Dehat. The area is covered by six Survey of India 1:25,000 scale topography sheets, the details of which are given in Table 5.1.

Some of the details of the Kanpur Nagar district cited above, were obtained from data furnished by source organisations including the Census of India, Survey of India, Central Ground Water Board, Geological Survey of India and other government agencies including the National Atlas and Thematic Mapping Organisation.

Table 5.1: List of Maps Used for the Study

MAP INDEX NO.	PUBLICATION YEAR	ORGANISATION
1) 63B	1982	Survey of India, Dehra Dun.
2) 63B/2/SE	1983	Survey of India, Dehra Dun.
3) 63B/3/NE	1983	Survey of India, Dehra Dun.
4) 63B/6/SW	1982	Survey of India, Dehra Dun.
5) 63B/6/SE	1982	Survey of India, Dehra Dun.
6) 63B/7/NW	1983	Survey of India, Dehra Dun.
7) 63B/7/NE	1979	Survey of India, Dehra Dun.
8) 026-NA/DP-2000-96	1996	NATMO, Calcutta.

5.3 DATA ACQUISITION

Spatial data exist mostly in map form. Maps are, in fact, well-known tools for recording, storing and retrieving spatial data. Calkins (1975), enlists the characteristics of maps that are of importance in any computerised application of mapped data as follows.

1) Maps contain very large volumes of data.
2) Spatial relationship between entities are explicitly represented in the map structure.
3) Attribute data, associated with the spatial entities, can be represented by a variety of techniques, e.g., shading, explicit feature codes, variable line widths, etc.
4) Maps can be used manually, frequently without any special equipment.

In short, the field of cartography has, over the years, moved toward the optimisation of the recording, storage, and retrieval of spatial data in a graphic format. Calkins (1975), states that the design and implementation of computer techniques to replace

maps, must adequately consider the above items and include methods for accomplishing all the tasks implicit in the map characteristics as identified above.

There are at least four basic procedures for automating cartographic data. They are: manual digitising, automatic scanning, entry of co-ordinates using co-ordinate geometry and conversion from previously automated information.

For the present study, manual digitisation was the mode of data input, most extensively used. The elevation contour lines, the road/rail networks, the district boundaries between Kanpur Nagar, Kanpur Dehat and Unnao districts were all manually digitised as line segments. These information were acquired from the 1:25,000 Survey of India topography sheets, the details of which are furnished in Table 5.1.

Soil data of the study area were acquired from the maps supplied by the National Atlas and Thematic Mapping Organisation (NATMO), Calcutta. The boundaries of the various classes were first digitised and then the individual blocks of soil were identified as polygons. The soil map furnished data at a very coarse scale (1:500,000), and as such only three different classes of soil could be discerned, viz., Alfisols, Aridisols and Entisols.

The transformation module of a GIS, as discussed in Section 4.3.2, supports the modelling of data already incorporated in the database to derive information which in turn can be stored as a separate overlay. This particular property of the ILWIS package has been used to derive the information about the slope of the study area, from the database of elevation. This information has been stored in a separate database.

Information about the groundwater table depths in the study area, were available from the drill log reports of U.P. *Jal Nigam* for sampling points, at various locations in the area. The co-ordinates of these points, along with their respective attributes (groundwater table depths) were entered into the system.

5.4 CHANGE OF MAP PROJECTION

The operation of digitisation starts with the identification and digitising of control points on the map. It is required, to establish the relationship between the map co-ordinates (usually in latitude-longitude format) and digitiser co-ordinates. In ILWIS this relationship is assumed to be linear. This implies that in principle, only maps with square and rectangular graticules can be used. Another feature of this particular package is that it assumes all linear measurements in metres. Thus, an *apriori* transformation of the map co-ordinates into planar metric co-ordinates is required for the control points. This conversion programme is also supported by ILWIS itself, on a menu-driven basis, where the source and the target projection systems are taken as the manual inputs.

Regardless of whether the earth is considered a sphere or a spheroid, it is not possible to develop its surface exactly onto a plane and whatever procedure is used to represent

an area on a map, there will always be some distortions. To minimise the distortions as well as to develop several possibilities, points on the map are represented in terms of parallels of latitude and meridians of longitude. Position on the earth in terms of latitude and longitude (e.g. Kanpur city centre is approximately at latitude 26°27'30''N and longitude 80°30'00''E) is transformed into scaled linear dimensions on the map. This is accomplished by using the dimensions of the earth and a selected set of criteria for representing the curved earth on a flat map. Such a transformation from latitude and longitude (ϕ and λ respectively) to a map's X and Y co-ordinates is the function of map projections.

Although all map projections are carried out by computing X and Y for each pair of ϕ and λ, there are two methods of projection: geometric and mathematical. In geometric projection, a surface that can be developed into a plane (such as a plane, a cone or a cylinder) is selected such that it either cuts or is tangent to the earth. A point is then selected as the projection centre from which straight lines are connected to points on the earth and extended until they intersect the selected mapping surface. In mathematical projection, there is no one particular projection point; instead, an equation is used to compute the location, X and Y of the point on the map from its position, ϕ and λ, on the earth.

For countries like India, having a large areal (North-South and East-West) extent, the Lambert Conformal Conic projection system is adopted (Rampal, 1985). It is a geometric projection technique, which was developed by Johann Heinrich Lambert in 1772. It is a conic projection with two standard parallels. Meridians are straight lines meeting at a point outside the map limits; parallels are arcs of concentric circles, and both sets of lines meet at right angles. The further details of this particular projection technique are furnished elsewhere (Anderson and Mikhail, 1985).

The present study was carried out over a particular area of the Kanpur Nagar district (the details are furnished in Section 5.2), but the possibility of carrying out similar studies over other areas of the district was kept in mind. For this purpose, the first and second standard parallels and the central meridian (required for the Lambertian projection) were selected accordingly. The parallels of latitude, roughly bounding the district, were selected as the standard parallels, and the mean of the meridians of longitude, bounding the district, was selected as the central meridian (the approximate geographical extents of the Kanpur Nagar district were obtained from the 1:250,000 Survey of India topography sheet No. 63B). The flowchart of the operation and the coefficients of the transformation are given in Figure 5.2.

(Notes on the flowcharts: A number of flowcharts have been included as a part of this thesis to provide the operational details of the programmes supported by the ILWIS package. In these flowcharts, the bullet symbol (•) has been used to indicate the sequential progress of the programmes. The indents, preceding the bullet symbols, have been used to indicate the hierarchies in the programme structure. The name of the main module (e.g., VECTOR), names of the various programmes and sub-programmes of the module (e.g., ChangeProjection), system queries (e.g., First Standard Parallel) or outputs (e.g., INITIALIZATION PARAMETERS...) follows the

bullet symbol. The name of the main module follows the bullet symbol on the first line of the flowcharts. ILWIS is an interactive package, and as such, most of the system queries are supported by a default option or a set of alternatives which can either be confirmed or rejected. The response to all system queries are depicted in bold italics (e.g., ***Lambert Conf Conic***) in the flowcharts. In case the default options are confirmed, the ↵ symbol has been used. The names of the maps created in the ILWIS environment, for the present study, are given self-explanatory names and are referred to, in the flowcharts in uppercase bold italics, e.g., ***SOIL***, ***CONTOUR***, etc. Some of the flowcharts are followed by a set of footnotes for the explanation and/or justifications of the system queries and the query inputs)

- VECTOR
  - ChangeProjection
    - Manual
      - Source Projection : ***Geographic***
      - Target Projection : ***Lambert Conf Conic***
        - Select Ellipsoid: ***Everest*** (1830)
          - First Standard Parallel : ***26°10'00''N***
          - Second Standard Parallel : ***26°38'00''N***
          - Central Meridian : ***80°21'30''W***
          - Latitude of Origin : ***26°10'00''N***
          - False Easting : ***0***
          - False Northing : ***·0***
    - INITIALIZATION PARAMETERS (LAMBERT CONFORMAL CONIC PROJECTION)

      SEMI-MAJOR AXIS OF ELLIPSOID = 6377276.3000 METERS
      ECCENTRICITY SQUARED = 0.0066378367
      LATITUDE OF 1ST ST. PARALLEL = 026 09 59.9999
      LATITUDE OF 2ND ST. PARALLEL = 026 37 59.9999
      LONGITUDE OF ORIGIN = 080 21 29.9999
      LATITUDE OF ORIGIN = 026 09 59.9999
      FALSE EASTING = 0.0000 METERS
      FALSE NORTHING = 0.0000 METERS
      - Input Co-ordinates

        Latitude :***26°32'30''N***
        Longitude :***80°25'00''E***
      - Result of transformation X: 5812 Y: 41545

        Again (y,n)? *y*
      - Input Co-ordinates

        Latitude :***26°22'30''N***
        Longitude :***80°12'30''E***
        Result of transformation X: -14967 Y: 23088
        Again (y,n)? ***n***

Figure 5.2: Flowchart for Change of Projection System

The results of transformation of the upper-right and lower-left corners of the study area are shown in Figure 5.2. Actually, for the study area, a total of twelve control points were transformed from the geographical to the metric co-ordinates. The details of these points along with the reference of the Survey of India topography sheets on which they were identified are given in the Table 5.2.

Maps that were acquired from NATMO, were without geographical co-ordinates. For digitising from those maps, transformation was carried out as follows: First the minimum bounding rectangle, bounding the Kanpur Nagar district were drawn, using a drafter. Similar bounding rectangles were drawn around the map of the district on Survey of India topography sheet No. 63 B (at 1:250,000 scale) and the corner co-

ordinates of the rectangle were graphically obtained. Transformation was carried out on those co-ordinates with the same transformation coefficients (as shown in Figure 5.2). The results are presented in Table 5.3. On the NATMO maps, the corner points of the bounding rectangle were geo-referenced with the metric co-ordinates obtained from the transformation (Table 5.3).

Table 5.2: Geographical and Metric Co-ordinates of Control Points

MAP INDEX NO.	LATITUDE (N)	LONGITUDE (E)	X (m)	Y (m)
63 B/2/SE	26°32'30"	80°12'30"	-14946	41552
	26°32'30"	80°15'00"	-10794	41548
	26°30'00"	80°15'00"	-10798	36932
	26°30'00"	80°12'30"	-14951	36936
63 B/6/SW	26°32'30"	80°22'30"	1661	41543
	26°30'00"	80°22'30"	1661	36927
63 B/6/SE	26°32'30"	80°25'00"	5812	41545
63 B/3/NE	26°22'30"	80°15'00"	-10810	23084
	26°22'30"	80°12'30"	-14967	23088
63 B/7/NW	26°22'30"	80°22'30"	1663	23080
63 B/7/NE	26°30'00"	80°25'00"	5814	36929
	26°22'30"	80°25'00"	5821	23081

Table 5.3: Geographical and Metric Co-ordinates of Rectangle Bounding the Kanpur Nagar District

MAP INDEX NO.	LATITUDE (N)	LONGITUDE (E)	X (m)	Y (m)
63 B	26°10'20"	80°07'16"	-23712	637
	26°38'06"	80°07'16"	-23618	51905
	26°38'06"	80°35'38"	-23452	51905
	26°10'20"	80°35'38"	-23545	637

With the control points, obtained for the different maps, by the change of projection, the actual process of digitisation was started, the working details of which are furnished in Section 5.5.

5.5 MANUAL DIGITISATION

Nearly all current operation of scientific and operational spatial data handling systems must deal with the complex analogue to digital conversion process by which map sheets are changed into clean, useable digital files. This transformation is accomplished by means of either manual or automatic digitisation. The latter has been shown to be economical only for very large data volumes and practical only when the map documents being scanned have been prepared according to a strict set of specifications. For many operational activities, both governmental and private, and for nearly all scientific applications, manual digitisation represents the primary method for enter-

ing map data into the GIS (Peuquet and Boyle, 1984). While considerable work has been done with newer technologies, the overwhelming majority of cartographic data entry is now done by manual digitisation (Dangermond, 1988). Dangermond (1988), enlists the reasons for this as follows.

1) One may not be able to remove the maps to where a scanner is available for doing the automatic conversion.
2) Records may not be in a form that can be scanned (e.g., maps are of poor quality, in poor condition or have errors).
3) The cartographic features may be too few on a single map to make it practical to scan.
4) A scanner may be unable to distinguish the features to be captured from the surrounding graphic information on the display.
5) Scanning may not provide the required data precision.
6) Scanning may be more expensive than manual digitisation, considering all cost/performance issues.

Dangermond (1988), also enlists the various advantages of manual digitisation as follows.

1) Low capital cost, low-cost labour and great flexibility and adaptability.
2) While it is a time-consuming procedure, the technique is simple.
3) With modern database error checking softwares, the quality of the information is high.
4) Interactive entry and editing can be done while users work on the cartographic data.
5) Errors on the basic map can be easily discovered and updated while in the process of entering the information.
6) Digitising devices are very reliable.

In view of these advantages, Dangermond (1988) concludes that digital scanning will not replace manual digitising for a considerable time.

The ILWIS package supports manual digitising using an electromagnetic, electrostatic device called a digitiser. A digitiser system, primarily consists of a digitising tablet and a cursor or puck. The digitiser converts the movements of the cursor or point locator into electrically identified locations on the tablet which are read directly into the computer. Digitisers are usually designed to be very accurate and can be programmed with a minicomputer to capture data in varying formats of points, lines and polygons in either a point by point mode or by a continuous mode incrementing by distance moved by the cursor on the digitiser tablet. For the present study, the DATATAB II digitising system, manufactured by ALTEK Corporation, has been used (details of the system are given in DATATAB II User's Guide, 1994).

Apart from digitising using a paper map, the ILWIS package, as discussed in Section 4.9.1, supports the facility of on-screen digitising using a raster image displayed on the graphics screen. In this way, interpretations can be made from scanned photographs or satellite images. A raster image has to fulfil certain criteria to be used as a background for digitising (the details of which are given in the ILWIS 1.4 User's Manual, 1993) and in the ILWIS environment, it is called a ***backdrop image***. For the present study however, on-screen digitisation has not been carried out.

The digitisation programme has its own menu structure. The menus appear on the screen in blocks of four commands. Commands can be selected by pressing one of the four buttons of the digitiser. The numbers preceding the commands indicate the cursor button that should be pressed to select a particular option. At certain points however, the user is asked to enter commands using the keyboard in order to (1) confirm an action to be undertaken by the programme; (2) specify file names; (3) specify names, codes and/or colours of points, lines and polygons; and/or (4) specify control points. The programme is divided into three parts or modes: the mode for digitising and managing segments; the mode for digitising and displaying points and the mode for polygonising vector maps and managing polygon files. An overview of the command block structure can be found in the ILWIS 1.4 User's Manual (1993). The stepwise operational procedure and the key features of the digitisation programme are as follows:

5.5.1 Co-ordinate Transformation

A link between the map and the digitiser co-ordinates has to be made, in order to digitise and manipulate map data (with the map, fixed on the digitising tablet), using the co-ordinate system of the map. This can be done by specifying control points (discussed in Section 5.4). When a control point is digitised, its real-world (metric) co-ordinates are entered into the system, to calculate the transformation between digitiser and real-world co-ordinates. Control points need to be points, for which the co-ordinates can be determined accurately; they can well be grid line intersection or triangulation points. In the present study, the corner points of the multiple maps used were selected as the control points. The metric co-ordinates of these points were previously determined by transformation from the geographical to Lambert Conformal Conic projection (discussed in Section 5.4). A minimum of three points have to be digitised, and an *affine* transformation, involving the rotation and scaling of the co-ordinate axes is carried out. The transformation coefficients are displayed on the screen in order to check the results of the transformation and to ensure that the control points have been correctly inserted. The value of sigma (in digitiser units), calculated along with the transformation coefficients gives the measure of the accuracy with which the control points have been digitised. If the accuracy is not acceptable, provisions exist for deletion or addition of existing and new control points respectively.

For the present study the value of sigma was restricted to ±3 throughout. Six Survey of India (1:25,000) topography sheets were used for the study area, and there were a total of twelve control points, details of which are furnished in Table 5.2. All these points were digitised simultaneously, and the results of transformation were stored in the same file. When operation was to be carried out on any particular map, that file

was loaded onto the system and from the list of the twelve control points, the four corresponding to that map were selected for the co-ordinate transformation.

The NATMO maps were digitised, using the four control points as shown in Table 5.3.

5.5.2 Digitisation Modes

After a satisfactory co-ordinate transformation, the digitisation programme of ILWIS is ready to accept positional information within a user-defined window and on the transformed co-ordinate system. As mentioned earlier, three modes of digitisation are available with ILWIS, viz., the ***Segment mode***, the ***Point mode*** and the ***Polygon mode*** (the bold italics have been used to distinguish ILWIS command block options).

(a) The *Segment mode* of digitisation

Segments can be digitised in two ways: curved segments are digitised by pressing the button of the cursor continuously. In this way the co-ordinates are recorded continuously. This way of digitising is called the *stream-mode* of segment digitisation. Straight lines are digitised by pressing the button of the cursor non- continuously. In this way the co-ordinates are only recorded when and where the button is pressed. In practice this means that the button is pressed only at the begin and end points of a line. This way of digitising is called the *point-mode* of segment digitisation.

In the present study, the district boundaries, the contour lines, the boundaries of the different soil classes and some of the tortuous road and rail networks have been digitised in the stream-mode, while the majority of the road and rail networks and the frame of the study area were digitised in the point-mode.

(i) Code and Mask

Two other singular features of Segment mode digitisation are codes and masks.

Digitised segments can be assigned an attribute ***Code***. For instance, a segment representing a road could have a code *road*, to differentiate it from a segment representing a river, having a code *river*. When an isoline map is digitised, the segments have the numerical value of the isoline as the code (e.g., a 120 metres contour line has to be digitised with the code *120*). The code should be specified, preferably, before digitising the segment (the details of operation are provided in the ILWIS 1.4 User's Manual, 1993). All segments digitised, are assigned the current code automatically. It is possible to change the code of a given segment later. A segment can only have one code. If no code has been specified, all segments will have a default code (B00). One concept that is quite typically associated with GIS activities is the storage of data in *layers*. The facility of codes contribute significantly in this respect.

It is not always necessary to display all segments at the same time. It may be useful to display only the segments with specific code(s). In a ***Mask***, the codes of the segments which should be displayed can be specified. Multiple codes can be specified in one

mask. The current code should always be specified in the mask, to be able to see the currently digitised segments.

(ii) Editing errors

The ILWIS package supports the facility of editing errors incurred during the process of segment digitisation. Accurate digitisation of segments are vital for the creation of a polygon map out of a segment map. The ILWIS User's Manual (1993) lists (and explains with illustrations) the following defects or errors that can possibly occur in a segment map.

1) *Dead end in segment:* One segment has not been connected to another. A gap exists between one segment and the one adjacent to it.
2) *Missing node in intersection:* This means that at the intersection of two or more segments no node point has been defined.
3) *Segment overlay at node:* Two segments, departing from one node point, are overlaying each other.
4) *Segment overlaying segment:* Two segments are overlaying each other. This may happen when a line has been digitised twice.
5) *Hidden node in segment:* A segment is doubled between two nodes.

In ILWIS there are two ways of correcting these errors. One can use the command block that attempts to rectify the errors automatically (***AutoEdit***), or it can be done manually, by reverting back to the segment mode. For the present study, the latter was usually carried out. The automatic editing mode cannot guarantee the proper rectification of errors and in fact there has been instances where worse errors incurred, when automatic rectification was attempted. Manual rectification offers the precision, which automatic editing lacks. Moreover with zooming facilities (***Change Window***), and facilities like ***Snap*** and ***Retouch*** (ILWIS 1.4 User's Manual, 1993), manual editing, though laborious, is rendered an accurate operation.

(iii) Files created

An ILWIS segment map consists of 3 separate files, all with the same name, but with different extensions:

1) [FILENAME].**CRD** :Contains all points between begin and end points of a segment.
2) [FILENAME].**SEG** :Contains codes, begin and end points and link to intermediate points.
3) [FILENAME].**SLG** :Contains link to polygon maps (if any) made from the segment map.

In the present study, the following maps were digitised in the segment mode.

1) ***CONTOUR:*** Containing the contour lines of the study area as well as the study area boundary. Used codes: *110, 115, 120, 125, frame*. The numbers represent the contour value.

2) ***SOIL:*** Containing the lines defining the different soil types as well as the rectangle bounding the district extremities. Used codes: *soiltypes, frame.*

3) ***REGION:*** Containing the political boundaries of the three districts, Kanpur Nagar, Kanpur Dehat and Unnao, that fall inside the study area and the study area boundary. Used codes: *bound, frame.*

4) ***TRANS:*** Containing the road and rail networks in the study area. National and state highways have been digitised along with the ordinary roads. The different rail networks has not been differentiated. The boundary of the study area has been digitised. Used codes: *NH2, NH25, SH17, SH22, roads, rails, frame* (*NH* denotes national highways and *SH* denotes state highways). Two other segment files were derived from ***TRANS***. One of them (***STROADS***), contained only the information of the road networks, including the national and the state highways in the study area. The other (***STRAILS***), contained information about the rail networks. Both these files also contained the frame bounding the study area.

5) ***WATERS:*** Containing information about the water bodies, enclosed and linear, in the study area, including rivers, streams, canals, lakes. The narrow features have been digitised as single lines. Used codes: *water, frame.*

(b) The *Point mode* of digitisation

The operations in the point mode are similar to those in the segment mode except for the fact that points are not identified by codes as applicable to segments, but by an alphanumeric identifier (up to 15 characters). The alphanumeric point identification is displayed on the screen, and the position of the digitised point is indicated by a + symbol. The points digitised can be stored for future reference in a *point file* which are created on command and new points can be added and erroneous points can be deleted from the screen as well as the file.

(i) File created

A point file is created on command for the storage of the point information in ILWIS with a default extension:

[FILENAME].PNT : Contains information about the position of the point in the *X-Y* plane. The co-ordinates are stored as real numbers, with the long integer identifier (*!*) and the alphanumeric identifier of the point (stored as ***Name$***) which is a string variable with the string identifier (***$***).

In the present study, the following point files were made.

1) ***CONTOUR:*** Containing the information about the elevation of benchmark and triangulated heights at different points in the study area. The heights are stored as the alphanumeric identifiers, which are later converted to numeric characters for mathematical operations in the RASTER module (discussed in Section 6.5).

2) *WATER:* Contains the information about the groundwater table depths at different points in the study area. Initially the name of the sampling locations were stored as the identifier, and later that file was edited to store the value of the depth, as numeric characters, corresponding to the respective sampling point.

(c) The *Polygon mode* of digitisation

The polygon mode allows the creation of one or more polygon maps out of a segment map, i.e., to create topology, calculate area and perimeter of polygons, to name, rename, and re-colour polygons, and to display them. Before a topology can be created, the segments have to be checked for errors. To illustrate the operational details of this particular programme, the steps followed in creating the *polygon file* ***SOIL*** is given by the flowchart in Figure 5.3. The pre-requisites for the creation of the polygon file are the 3 segment files with the default extensions.

- VECTOR
    - Digitize

      Backdrop image name (ENTER = none): ↵

      Enter segment file: ***SOIL***
        - Edit (without map)
            - Polygon mode
                - Check/Make/Update
                    - Check Segments
                        - Mask[*]: ↵ *1

                          Segments OK...

                          Press any key to continue↵
                    - Make/Update Polygons ↵
                        - PolygonFileName [SOIL]? ↵

            < Polygon Generator >

            Mask[*]: ↵

            Creating Polygon File...
                    - Enter Names
                        - Name Prompt *2

*1. *All the codes were selected for polygonisation. The segment errors if present are detected at following this step and needs to be rectified.*

*2. *The different polygons,* in succession and *representing the various soil types were flashed their respective names were entered manually: **ALFISOLS, ARIDISOLS, ENTISOLS**.*

Figure 5.3: Flowchart for Making Polygon File

Following the flowchart, shown in Figure 5.3, the polygon file ***SOIL*** was created, with the information of the different polygons (soil types), their names and a default colour is assigned to each based on the first alphabet of the polygon name. The polygons remain displayed on the colour monitor. The system is returned to the VECTOR

main module. In order to change the colours of the different soil types to closely match the colours of the map, the flowchart given in Figure 5.4 was followed.

Following this step, the table with the polygon names and colour is displayed with the keyboard based editing facility to change the names and colour of the different polygons.

- VECTOR
    - Display&Change
        - Polygons
          Enter polygon map name: ***SOIL***
            - Change Name&Col
              Enter window name: ^{*1}
              Use existing co-ordinate system?(y,n) *y*

*1. *The screen with polygons displayed.*

Figure 5.4: Flowchart for Changing Name and Colour of Polygons

For the present study, the colour codes for Alfisols, Aridisols and Entisols were 3, 7 and 15 respectively with ***2*4 Standard*** colour look-up table (details in ILWIS 1.4 User's Manual, 1993). Although only the polygon file ***SOIL*** has been referred to, other polygon maps were also made in a similar manner. The polygons of the ***REGION*** polygon file, represent the various districts that fall within the study area, viz., Kanpur Nagar, Kanpur Dehat and Unnao and the polygon file ***WBPOLY*** consists of the polygons made out of digitising the enclosed water bodies in the study area.

(i) Files created

An ILWIS polygon map consists of the files of the segment map, plus some extra maps:

1) [FILENAME].**POL** : Contains name, colour, start segment and number of segments, area and perimeter of each polygon.
2) [FILENAME].**TOP** : Contains topology for each segments, forward and backward links and right and left polygons.
3) [FILENAME].**PLG** : Contains link to segment map.
4) [FILENAME].**DAT** : Contains data table from polygons.
5) [FILENAME].**PLC** : Contains polygon colours table.

In the present study, the following polygon files have been made.

1) ***SOIL:*** Contains information about the different classes of soil in the study area.
2) ***REGION:*** Contains information about the different districts that fall inside the study area.

3) *WBPOLY:* Contains information about the enclosed water bodies in the study area, namely, ponds, lakes, streams and rivers.

As discussed earlier, manual digitisation, represents just one mode of data input into a GIS environment. However, for the present study, this mode has been exclusively used, for the input of data from the real-world. GIS also provide a very large range of analysis capabilities that enables operation on the topology or spatial aspects of the geographical data, on the non-spatial attributes of these data, or on non-spatial and spatial attributes combined. The ILWIS package provides these analysis capabilities in such a way that the user can work interactively in order to perform the analyses and syntheses required. As mentioned in Section 4.9, ILWIS is a raster-based GIS package, i.e., most of the spatial analyses and modelling operations are carried out in the raster domain. Manual digitisation represents a vector format of data input. Thus for any spatial operations to be carried out, the vector files needs to be converted into the raster format.

5.6 RASTER CONVERSION

The operation of raster conversion can be viewed as the draping of a vector map with a gridded mesh. The cells in this grid have a user-defined size, the pixel size and depends on the desired resolution of the raster map. The pixel size determines how large is the map area that is represented as a raster element on the screen. The ILWIS package supports the conversion of maps in the vector format (that is, the maps digitised) to maps in the raster format by a set of programmes in the VECTOR module. There are three different types of raster maps, each having the capacity to store a different range of pixel values. They are as follows.

1) *Bit raster map*: Each pixel can have a value of 0 or 1 (true/false, on/off, exist/not exist). Eight pixels of a bit map require 1 byte of disk space for storage.
2) *Byte raster map*: Each pixel can have a value between 0 and 255. Thus in a byte map, 256 different units can be differentiated. Each pixel requires 1 byte of disk space for storage.
3) *Integer raster map*: In an integer map values between -32767 and 32767 can be stored. This range is rendered flexible by using the *scale factor*. For instance, a scale factor of -2 indicates the reduction of the range from -327.67 to 327.67 and a scale of +1 indicates the range -327670 to 327670. Integer maps are useful for storing real numbers with high accuracy. Each pixel in an integer map require 2 bytes of disk space for storage.

The working details of these programmes are provided in the following sections.

5.6.1 Conversion from Segment Files

The VECTOR module of ILWIS, supports a programme that converts segment maps to raster maps. The pixel and the portion of the map to be converted are user-defined.

The transformation from the existing segment map can also be copied onto the raster map. The package also offers the option to assign attribute values to the rasterised segments. This implies that the segment codes can be converted to numbers (i.e. pixel values) in the resulting raster map. The portions in the segment map without codes (blank portions) gets a default value of zero (0) in the raster map. The features (codes) which are desired to be kept undefined, i.e., without any attribute value, for example the frame of a segment map, are denoted by a note of interrogation (?), in the list where the attribute values are specified. The working details of the operation are illustrated by the example of the rasterisation of the segment map ***CONTOUR***, given by the flowchart shown in Figure 5.5.

Although only the rasterisation of the segment file ***CONTOUR*** has been discussed here, three other segment files, namely, the ones derived from the segment file ***TRANS*** (i.e., ***STROADS*** and ***STRAILS***) and the segment file ***WATERS*** have also been rasterised.

In case of ***STROADS*** and ***STRAILS***, the frame of the study area was rasterised with an attribute value of 1 and all the other linear features were given an attribute value of 0. This was done for two reasons, and the justifications are furnished in Section 6.2 and Section 7.3.3. It is to be noted that when rasterising these maps, the output raster map, by default, were stored as *Byte* raster maps, and the pixels were having two values, 0 and 1 (binary files). Storing only two pixel values, 0 and 1 is typical of *Bit* raster maps. Thus, in view of the smaller disk space required for storing binary files as *Bit* raster maps, rather than *Byte* raster maps, conversion of these maps from *Byte* raster map type to the *Bit* raster map type was carried out. The details of these conversions are furnished in the next chapter, Section 6.5. The co-ordinate transformation for these maps were copied from the existing raster map ***STCLINE***. The other segment file rasterised was the one containing the information about the water bodies. The resulting raster map ***WBSEG*** also was initially rasterised as a *Byte* raster map by default, and was later converted into a *Bit* raster map, with the boundaries of the water bodies in the study area having an attribute of 0 and the frame, 1 (the justification of these values are furnished in Section 6.2).

5.6.2 Conversion from Point Files

The VECTOR module also supports the creation of raster maps from point tables, containing the spatial location of the points in the *X-Y* plane and, optionally, one or more attribute columns. Pixels in the raster map that represent points, can have as value an attribute value (defined in the attribute column of the point file), a record number (defined in the point table), or be *1*. Pixels in the raster map that do not represent a point will have either a value of *0* (in a *Byte* raster map) or *?* (undefined, in an *Integer* raster map).

In the present study, the point files that were rasterised, include the one that contained information about the groundwater table depths at various locations in the study area, i.e., ***WATER***, and the one containing information about the triangulated point heights and benchmarks at various locations in the study area, i.e., ***CONTOUR***. It is to be noted that since both these table contained numerical values, in order to store these

numbers as the attribute values, the point table had to be edited, whereby the numbers which were stored, by default, as string characters (by the string character identifier *S*) in the point file during point mode digitisation, discussed in Section 5.5.2(b), were restored as real numbers or integers (with the identifiers & and % respectively). Depending upon the range of these values, the resulting raster map type was defined. automatically. The working details of rasterisation from point tables is illustrated by the flowchart for the rasterisation of the point file ***WATER*** shown in Figure 5.6.

In the present study, the two maps rasterised from point tables were of two types: the raster map derived from the point file ***WATER***, i.e., ***STWPNT*** was of the *Integer* type with a scale factor of -3; and the map derived from the point file ***CONTOUR***, i.e., ***STCPNT*** was a *Byte* raster map.

5.6.3 Conversion from Polygon Files

In ILWIS, the conversion of polygon maps to raster maps is carried out by a programme similar to the one that creates raster maps from segment files in the VECTOR module. In this programme also, the pixel size and the portion of the map to be rasterised is user-defined and transformation can be copied from existing raster maps. Either separate polygons or group of polygons having the same name can be taken as unit. This means that polygons can be rasterised as unique elements with each polygon being treated as a separate mapping unit and getting a unique pixel value, or polygons having the same name can be assigned the same pixel value. Attribute maps can be made with manual entry of the pixel values for each polygon. If attribute maps are not made, the pixel values will be assigned to the mapping units in alphabetical order of the mapping unit names. The working details of the conversions operation is illustrated by the flowchart for rasterising the polygon file ***REGION*** shown in Figure 5.7.

It is to be noted that the raster map ***REGION*** consisted of only two pixel values, 0 and 1. Hence it could as well be stored as a *Bit* map. The *Integer* raster map was created by default, and it occupied a disk space which was 16 times more than that required by a *Bit* map. Conversion of the *Integer* raster map into a *Bit* map was thus desirable. This was carried out in the RASTER module and the *Bit* raster map was also stored by the same name ***REGION***. The details of this operation are furnished in Section 6.5.
In the present study, as mentioned earlier, the study area covered parts of three districts, namely: Kanpur Dehat, Kanpur Nagar and Unnao. The raster map generated from the polygon map ***REGION***, was assigned, by the above operation, values of 0 for parts in the study area falling outside the Kanpur Nagar district and a value of 1 for parts within the district. The polygon file containing information about the enclosed water bodies in the study area, ***WBPOLY***, was rasterised with the water bodies being assigned a value of 0 and the surrounding land, a value of 1. The polygon file ***SOIL*** was also rasterised, with different values being assigned to the different soil cover types, in a similar way. The image of the raster map is given in the Appendix (Plate A.1).

- VECTOR
  - RASTERIZE
    - SegmentToRaster
      - Enter segment map name: ***CONTOUR***
        Create attribute map (y,n) *y*
        Enter values manually? (y,n) *y*
        <u>Enter missing values:</u>
        110 ***110.0***
        115 ***115.0***
        120 ***120.0***
        125 ***125.0***
        frame ***?***
        Byte map
        - Enter output raster map name: ***STCLINE***
          Copy coordinate transformation from existing map?(y,n)***n*** *1
          <u>Map dimensions</u>
          Min X :-14974
          Min Y :23078
          Max X :7870
          Max Y :43397

          Meters per pixel: *25* *2
          Lower left corner
          X :***-14950***
          Y :***23075***
          Upper right corner
          X :***5825***
          Y :***41550***

(Using a gridded mesh of **740** rows and **832** columns, the process of rasterisation starts.)

*1. *If this option is confirmed, the segments are rasterised on the same geo-reference as an existing raster map, the name of which is asked for. This means that the co-ordinate transformation, the number of lines and columns and the pixel size will be the same. However, in this case, the option is rejected, since no raster map exists as yet. The bounds, i.e., the co-ordinates of the corners of the map or map segment, and the pixel size (in meters) are asked for. The minimum pixel size acceptable is 1 metre. The default map dimensions are also displayed on the screen.*

*2. *This value determines the resolution of the output raster map. This means that an area of 25 square meters in the real-world is represented by 1 pixel in the raster map. Based on this value, the map dimensions are rounded off as its multiples. Thus the default co-ordinates of the lower left corner of the raster map become, -14950, 23075 and the upper right corner, 7875, 43400. However, an inspection of the actual metric map co-ordinates, i.e., the bound of the study area as calculated by the change of projection in Section 5.4, reveals that the upper right corner is over estimated. Thus when the bounds are asked for, the closest upper right corner co-ordinates are fed as inputs.*

Figure 5.5: Flowchart for Raterising Segment Maps

- VECTOR
  - Display&Change
    - Points
      - To Raster
        - Enter table name for point data: ***WATER***
          Use column of table as attribute value? (y,n) *y*
          Sum at all pixels? (y,n) ***n*** *1
          Size of points in pixels: ***1*** *2
          - Enter output map name: ***STWPNT***
            Copy transformation from existing map? (y,n) *y*
            Enter map name: ***STCLINE*** *3

**1. This option signifies that the pixel value will equal the attribute value of the point, but in case more than one point falls within the same raster element, the pixel value will be the attribute of the last point assigned to that element*

**2. This number indicates the number of pixel(s) that will be used to represent one point in the raster map.*

**3 Any of the previously rasterised maps can be used for the purpose. The path also has to be defined in case the map, in this case STCLINE, was stored in the same directory.*

Figure 5.6: Flowchart for Rasterising Point Maps

- VECTOR
  - RASTERIZE
    - PolygonToRaster
      Enter polygon map name: ***REGION***
      Use polygons instead of mapping units? (y,n) ***n***
      - Create attribute map? (y,n) ***y***
        Enter values manual? (y,n) ***y***
        Enter missing values:
        KANPUR DEHAT ***0*** *1
        KANPUR NAGAR ***1***
        UNNAO ***0***

        Scale = -4

        - Enter output raster map name: ***REGION***
          Copy coordinate transformation from existing map? (y,n) ***y***
          Enter map name: ***STCLINE***

**1. The justification of these values are furnished in Section 7.3.3.*

Figure 5.7: Flowchart for Rasterising Polygon Maps

5.6.4 Files Created in Rasterisation Operation

Three files are created in the rasterisation operation:

1) [FILENAME].**MPD:** Contains the map data, i.e., the pixel values. These are typically large files and proportional to the product of the number of rows and columns in the raster map.
2) [FILENAME].**MPI:** Contains the map information, i.e., the number of lines and columns, the maximum and the minimum pixel value, the map type (*Bit*, *Byte* or *Integer*), the scale factor in case of an *Integer* raster map and the co-ordinate transformation.
3) [FILENAME].**INF:** These files are created only if attribute maps are not created. In the present study however, attribute maps were not created for the conversion of either of the two polygon files. If created, the file contains the names of the originating polygons, their respective area and perimeter, and if the mapping units are rasterised, the number of polygons with the corresponding name.

Raster conversion is one of the last operations in the VECTOR module and it renders the spatial data entered into the system (by manual digitisation, in this case), in a form, such that modelling and other spatial analysis can be carried out on it. There are however, some analysis operations that can be carried out in the VECTOR module. For instance, the ILWIS package supports pattern analysis on a set of points in a point file. Spatial correlation of a point data set can also be estimated in this module. In the present study, the correlation and the semivariance of the groundwater table depth data were calculated in this module. The details of this operation are furnished in the next chapter, Section 6.3.1.

6. SPATIAL MODELLING OPERATIONS

6.1 GENERAL

Burrough (1986) states that the major difference between GIS and systems for computer-aided cartography, is the provision of capabilities for transforming the original spatial data in order to be able to answer particular queries. Some transformation capabilities, such as those necessary for data cleaning or updating, or for changing scales or projections, are common to both computer-aided cartography and GIS. Some of these capabilities of the ILWIS package, used for the present study, have been discussed in the previous chapters. GIS, however, provide a larger range of analysis capabilities that can operate on the topology or spatial aspects of geographical data, on the non-spatial attributes of these data, or on the non-spatial and the spatial attributes combined. These analysis capabilities are provided in a way, so as to allow the user to work interactively with the systems and perform the required analyses and syntheses.

Burrough (1986), presents a hierarchical schematic overview of the main kinds of capabilities that can be used for data utilisation and analysis in GIS (Figure 6.1). These capabilities range from simple methods for retrieving subsets of information from the database, through uni-variate and multivariate methods of data analysis, to spatial analyses using neighbourhood functions and interpolation methods. The concept of integrated multi-layered data analysis, is one which is quite typically associated with GIS. The modules for spatial modelling, offers this facility.

In the present study, only a limited number of spatial modelling capabilities of the ILWIS package have been utilised. The package supports a very large spectrum of spatial analysis techniques (details are given in Appendix VIII of ILWIS 1.4 User's manual, 1993) and furthermore, it supports the creation of an almost unlimited range of capabilities for data analysis by writing simple simulation programmes, in the systems environment. The database for the information about the slope of the study area was derived with the aid of such programmes.

- TRANSFORMATION
  - MAINTENANCE
    - Editing
    - Updating
  - UTILISATION AND ANALYSIS
    - Topology
      - rotation, translation
      - scale transformation, stretch
      - 3-D display
      - area, perimeter calculation
    - Properties
      - retrieval
      - logical/mathematical analyses
      - reclassification
        - uni-variate/hierarchical
        - multivariate/statistical
    - Topology + Properties
      - retrieval
      - overlay and intersection
      - region analysis
      - neighbourhood analysis
        - spreading
        - detecting shape, narrowness, etc.
        - interpolation
          - deterministic
            - B-splines
            - Thiessen polygons
            - inverse distance weights
          - statistical
            - trend surfaces
            - autocovariance analysis
            - Kriging, etc.

Figure 6.1: Schematic Overview of GIS Modelling Capabilities (Burrough, 1986)

6.2 CALCULATING DISTANCES

For the environmental management of any study area, as well as for decision-making purposes, it is useful to have the information about remoteness/accessibility of a particular location in the area, i.e., not only where a particular point is spatially located,

but also, how far or close it is from the nearest transportation network. Such information are stored in a *distance* map, a raster map in which the pixel values represent the distance from any particular feature of interest, for instance, roads, railway tracks, business centres, railway stations, etc.

For the present study, as mentioned earlier, the road and rail networks were digitised and stored as separate raster files. Using the set of programmes, supported by the ILWIS package, to calculate the distance of each pixel in a raster map, called the *source* map, from one or more user-defined points (pixels), the distance of each point in the study area from the nearest rail and road network was calculated.

The programmes calculate distances (in meters) for each pixel on a source raster map from user specified target pixels (representing roads, rails, etc.). A Thiessen map can be created optionally. In this case, however, it was not prepared. Weight factors can be introduced in the source map to simulate a resistance. The weight factors simulate the difficulty of crossing pixels which forms barriers, such as rivers. By including them in the distance calculation, a kind of accessibility map can be prepared. The higher the weight, the lesser accessible the pixel is. Unreachable points like rivers, dense forests or other impenetrable areas can be specified as non-target pixels by assigning a negative value as attribute. The source pixels are assigned an attribute value of 0 and all other non-source pixels, if no resistance are to be taken into account, as in the present case, are assigned an attribute value of 1.

This justifies the attribute values that were assigned to the features in the vector maps from which distance was calculated during the operation of rasterisation (e.g., ***STROADS***, ***STRAILS***, etc.).

At the start each non-target pixel (the pixels representing inaccessible points) gets a maximum distance from the source pixels. The distance calculation is a process in which for each pixel the distance from its neighbouring pixel is calculated using a 3x3 filter (Figure 6.2) with values 7, 5, 7, 5, 0, 5, 7, 5, 7 (filter coefficients). The quotient of 7/5 is assumed to be an approximation for $\sqrt{2}$ - the distance between two diagonally connected pixels when the raster cell size is 1.

7	5	7
5	0	5
7	5	7

Figure 6.2: Filter for Calculating Distance

For each neighbour of the current pixel, the distance (filter coefficient) times the weight assigned to the pixel (pixel value of maps from which distance calculation is to be carried out) is added to the current weighted distance value of the neighbour from the source. The minimum of the eight weighted distances and its own weighted distance to the source is assigned to the current central pixel. This is a recursive process, in which the output map has to be scanned forward and backward until no changes occur. Then the final calculation is carried out. The details of these programmes are furnished in the ILWIS 1.4 User's Manual (1993). The operational flowchart for the

preparation of the distance map ***ROADS*** from the source raster map ***STROADS*** is given in Figure 6.3. The image of ***ROADS*** is given in the Appendix (Plate A.3).

Distance maps were also prepared for calculating distances from rail networks and the water bodies in the study area. These maps were named ***RAILS*** and ***WBODY*** respectively. Image of the map ***RAILS*** is shown in Plate A.4 in the Appendix.

- RASTER
    - SPATIAL MODELLING
        - Distances
            - Compute also Thiessen map? (y,n) ***n***
                - Enter source map name: ***STROADS***
                  Enter distance map name: ***ROADS***
                  Enter scale: ***0***

Figure 6.3: Flowchart for Creating Distance Maps

There are some programmes in the ILWIS package which include the distance calculation subroutine. The programme which carries out interpolation from isolines is an example. Details of the interpolation function are discussed in Section 6.3.

6.3 SPATIAL INTERPOLATION/EXTRAPOLATION

The procedure of estimating the value of properties at unsampled sites, within the area covered by existing point observations is called *interpolation*. Estimating the value of a property at sites outside the area covered by existing observation is called *extrapolation*. The rationale behind spatial interpolation and extrapolation is the observation that, on average, points that are close together in space are more likely to have similar values of a particular property than points further apart.

Contours on a topographic map are constructed by following lines of equal height by aerial photographs, stereoscopically on a stereoplotter. But with point observations of environmental variables like groundwater for instance, the actual pattern of variation cannot be seen but can only be sampled at a set of points. The value of a property between data points, or beyond can be interpolated or extrapolated, only by fitting some plausible model of variation to the values at the data points and then calculating the values at the desired locations. At times, the values recorded at the data sampling points are such, that it is difficult to establish any plausible model of the variation. Such instances can be usually attributed to either abnormal natural variations or errors incurred during the process of data collection. In such cases, the practice of modelling the variation becomes meaningless.

The details of the techniques usually followed for interpolation/extrapolation from point data sets and isolines are furnished in the following sections.

6.3.1 From Point Data Set

In the present study, the groundwater depths in the study area were interpolated/extrapolated from the data set, representing the depths at the various sampling points, within the study area. In general, one of the most common methods of interpolating the value Z of a variable x_i, is to compute an average value from a local neighbourhood or *window* of n samples. In its simplest form, for regularly spaced data along a transect, the moving average for a point x_i in the centre of the symmetrical window is computed as:

$$Z(x) = \frac{1}{n}\sum_{i=i}^{n} Z(x_i) \qquad [6.1]$$

In two dimensions, the same formula would apply, with the sites x_i replaced by the vector X_i. As discussed above, observations located close together tend to be more alike, than observations spaced further apart. It is natural to feel that the contribution that a given sampling point makes to an average interpolated value at an unvisited site, should be weighted by a function of the distance between that observation and the site. Thus the *weighted moving average* can be computed as:

$$Z(x) = \sum_{i=1}^{n} \lambda_i Z(x_i) \text{ with } \sum_{i=1}^{n} \lambda_i = 1 \qquad [6.2]$$

where the weights λ_i are given by a function $\Phi(d)$, a function of distance $d(x, x_i)$, between the unvisited site x and sampling points x_i. A requirement is that $\Phi(d)$ maximises as $d \rightarrow 0$.

The *Kriging* method of interpolation, is generally applied for the interpolation of water table depths (Davis, 1986). It is an optimal interpolation technique based on the assumptions contained in the regionalised variable theory (Matheron, 1971). The Kriging method is similar to *weighted moving average* interpolation except that the weights are derived from a geo-statistical spatial analysis based on the sample *variogram.*

As discussed in Section 5.6, the ILWIS package supports the spatial analysis of point data sets in the VECTOR module. The programmes can be used to calculate the spatial correlation for a point data set, i.e., the degree to which, values of a particular parameter at a certain set of locations depend on the values of the same variable at some other location. Another parameter which these programmes calculate is the *semivariance (γ)*. It is an important parameter for carrying out Kriging interpolation and is estimated from the sample data as follows:

$$\gamma(h) = \frac{1}{2n}\sum_{i=1}^{n}\left[Z(x_i) - Z(x_i + h)\right]^2 \qquad [6.3]$$

where, n is the number of pairs of sample points separated by distance h. Sample spacing h is called the *lag*. A plot of $\gamma(h)$ against h is known as the sample variogram. It is an essential step on the way to determining optimal weights for interpolation. The details of the interpolation process are given elsewhere (e.g., Burrough, 1986; Davis, 1986).

For the present study, the semivariance and the correlation coefficients of the ground-water table data sets were calculated in the VECTOR module of ILWIS following the flowchart given in Figure 6.4.

- VECTOR
    - Display&Change
        - Points
            - Point Operations: ***Spatial Correlation***
                - Enter table name for point data: ***WATER***
                  Output Autocorrelation table: ***WATER***

Figure 6.4: Flowchart for Calculating Autocorrelation of Point Data Sets

The output of the spatial correlation operation is stored in a file with the extension .ACR (e.g., *WATER*.ACR) and consists of columns of distance between pairs of points, the number of pairs found within that distance of each other, the correlation coefficients and the semivariance for the corresponding distances. The graph of the correlation coefficients against the sample spacing, i.e., the distance h and the semivariogram can also be constructed by the ILWIS package.

However, from the semivariogram and the correlation coefficients, it was evident that the quality of the groundwater table data available for the present study, was of coarse details. The data set showed poor correlation. Thus Kriging was not applied, as it would not yield any significant result. However, the objective of the study as such, as discussed in Chapter 3, was to provide the working details of how spatial databases are developed in a GIS environment. With the availability of data of a better quality, the application of the same working procedures is expected to yield much more realistic results, as far as the real-world values are concerned. Thus interpolation was carried out, using the weighted average method with a convenient deterministic spatial function. The ILWIS package supports a set of interpolation methods from point data. The programmes perform gridding operations for randomly distributed points, stored in a point table with corresponding attribute values.In the present study, the weighted moving average interpolation from the groundwater depth point table was carried out following the flowchart given in Figure 6.5. The image of the resultant output map ***WATER*** is given in the Appendix (Plate A.2).

6.3.2 From Isolines

The significance of Digital Elevation Models are given in Section 6.4. The process of creating such models involve interpolation/extrapolation. As mentioned earlier, con-

tour lines are generated by following points of equal height on the earth's surface. The interpolation operation is involved in this process. Similar modelling is involved in generating a surface from these isolines. There are a set of standard modelling techniques available for the creation of the elevation models. Details of these techniques are given elsewhere (e.g., Burrough, 1986). The ILWIS package supports interpolation from contours (isolines), to generate a surface. The programmes can be used to create Digital Elevation Models, or similar elevation models, of any other continuously changing variable, from rasterised isolines.

- RASTER
    - SPATIAL MODELLING
        - INTERPOLATION
            - FromPoints
                - Enter table name for point data: ***WATER***
                  Enter output map name: ***WATER***
                  Copy transformation from existing map? (y,n) ***y***
                  Enter map name: ***STWPNT***
                  Gridding Method: ***Moving Average***
                  Use linear prediction? (y,n) ***n*** *1
                    - Enter limiting distance d0: ***24686.0*** *2
                      Weight Method: ***1/d^n -1*** *3
                      Enter value constant n: ***1*** *4

*1. *Linear prediction implies Kriging to be applied for interpolation operation. In this case the interpolation was performed using a user-defined weight formula. For each raster cell, the attribute value is calculated by the following formula.*

$$Z = \frac{\sum_{i=1}^{n} W_i Z_i}{\sum_{i=1}^{n} W_i}$$

Where Z = *Output attribute value for the current pixel*
n = *Number of points*
W_i = *Weight of point i (Weight function given below)*
Z = *Input attribute value of point i*

*2. *The limiting distance implies the maximum distance between the unvisited pixel and the pixels representing the sampling points, that are to be considered for the interpolation operation. This distance was calculated, such that the data from all the sampling points are considered for calculating the weighted average for all pixels in the study area.*

*3. *Exact weight function W:*
For $D \leq d0$ $W = \{1/(D/d0)^n\}-1$
For $D \geq d0$ $W = 0$
With: W = *Calculated weight*, $0 \leq W \leq \infty$
D = *Distance to a point measurement*
$d0$ = *Limiting distance*
n = *Constant factor*
(At the location of the given sampling points the output attribute value will be equal to the measured input value).

*4. *The exponent of the weight formula. The higher the value of n, smaller the influence over distance becomes and less smooth the result.*

Figure 6.5: Flowchart for Interpolation from Point Data

In these programmes, for each *undefined* pixel (pixels not having any attribute value, either representing empty space or features in the map or *codes* in vector maps, having

non-numeric attributes, and assigned the symbol *?* when rasterised) in the raster map, the distance to the two nearest contour lines is calculated linearly, in the same way as in the programme for calculating distances (as discussed in the previous section). A linear interpolation based on the two distances is carried out in the final stage of the programme. The operational flowchart is given for interpolation from the raster map *STCLINE* in Figure 6.6.

Such an interpolated raster map, containing the information about the elevations at every point in a study area, however, does not represent the real-world exactly. The accuracy, of course, depends primarily on the scale of the map from which the basic information is derived, as in this case the Survey of India 1:25,000 scale topography sheets. However, there are some errors incurred during the process of spatial interpolation as well. Any local undulations or information about the elevation between the contour lines, cannot be accounted for, by the simple linear interpolation. For the present study, it was thus decided to incorporate point information of benchmarks and triangulated heights also in the elevation database for a better representation of the real-world. As discussed earlier, these point information were manually digitised from the topography sheets for this purpose, and they were incorporated into the database by using some of the spatial manipulation facilities which, like most other GIS packages, is also supported by ILWIS. The details of these facilities are discussed in Section 6.5.

- RASTER
  - SPATIAL MODELLING
    - INTERPOLATION
      - From Isolines
        - Enter input map name: ***STCLINE***
          Enter output map name: ***STCONT***
          Integer Output Map? (y,n) *y*[*1]

*1. *For an input Byte raster map, this question is asked. In case it is confirmed, as in this case, the scale can be specified. In this case the scale was -2*

Figure 6.6: Flowchart for Interpolation from Isolines

6.4 DIGITAL ELEVATION MODELS

Unlike land-use, soil series or political boundary, the land form is usually perceived as a continually varying surface, which can be represented by isolines (contours). These contours can be effectively regarded as sets of closed, nested polygons. However, there are some exceptional cases (as in the present study), where the isolines are discontinuous due to physical obstructions, for example a river. Although sets of isolines are very suitable for the display of a continually varying surface, they are not particularly suitable for numerical analysis or modelling. Hence, other methods have been

developed, in order to be able to represent and to use effectively information about the continuous variation of an attribute over space.

Any digital representation of the continuous variation of relief over space is known as a *Digital Elevation Model* (DEM). The term digital terrain model (DTM) is also commonly used. But, Burrough (1986), feels that since the term *terrain* often implies attributes of a landscape, other than altitude of the land surface, the term DEM is preferred for models containing only elevation data. However, although such models were originally developed for modelling relief, they can be used to model the continuous variation of any other attribute over a two-dimensional surface.

Digital elevation models have many uses. Burrough (1986), enlists the important ones as follows.

1) Storage of elevation data for digital topographic maps in national databases.
2) Cut-and-fill problems in road design and other civil and military engineering projects.
3) Three-dimensional display of land forms for military purposes (weapon guidance systems, pilot training) and for landscape design and planning (landscape architecture).
4) For analysis of cross-country visibility (also for military and landscape planning purposes).
5) For planning routes of roads, location of dams, etc.
6) For statistical analysis and comparison of different kinds of terrain.
7) For computing slope maps, aspect maps, and slope profiles that can be used to prepare shaded relief maps, assist geomorphologic studies, or estimate erosion and run-off.
8) As a background for displaying thematic information or for combining relief data with thematic data such as soils, land-use or vegetation.
9) Provide data for image simulation models of landscapes and landscape processes.
10) By replacing altitude by any other continuously varying attribute, the model can represent surfaces of travel time, cost, population, indices of visual beauty, levels of pollution, groundwater levels, etc.

The ILWIS package supports the display of digital elevation models. The programme requires as input, a raster map, the DEM of which is to be displayed. It produces as output a line grid which can be filled optionally. The grid size, i.e., the number of lines per grid step is user-defined. It is possible to superimpose any *Byte* raster map on the perspective view. The view parameters are user defined. Thus the perspective of the observer (altitude, rotation, distance, vertical scale factor, etc.) in relation to the three-dimensional model can be adjusted.

In the present study, the digital elevation model of the study area was created using the programmes offered by the ILWIS package. The operational flowchart is given in Figures 6:7(a) and 6.7(b) (the details are furnished in ILWIS 1.4 User's Manual, 1993).

To accentuate the difference of elevations in the study area, the vertical scale factor was set to 100, as discussed above. To *view* these differences, a gridded mesh was draped on the digital elevation model displayed on the colour monitor. This was done by the ***Fast line grid*** option in the ***Apply View*** menu, as shown in Figure 6.7(b).

With regards to the visualisation of raster images, the concept of the colour *Look-Up Table* (LUT) is quite significant. Detailed explanations of LUTs are given elsewhere (e.g., Richards, 1994; Mather, 1987), but for the present purpose they can be looked upon as tables for assigning colours corresponding to the numbers stored in the raster maps, or the colour code of segment or polygon files. In the present study, the LUTs were chosen so as to make the images *visually* discernible. Although the ILWIS package includes the possibility of creating user-defined LUTs, for the present study, some of the standard look-up tables (also supported by ILWIS) were used. The list of the ILWIS colour look-up tables are provided in the ILWIS 1.4 User's Manual (1993).

- RASTER
  - VISUALIZATION
    - Display3D
      - Edit view*1

<u>Zoom angle</u>	<u>Height scale</u>
60.00	100.008

	<u>View at</u>	<u>Location</u>
X-Coor :	-4562	88392
Y-Coor :	32312	-67369
Height :	125	475

<u>Distance</u>		<u>Rotation</u>
140720	Horiz :	43.00
	Vert :	14.40

      - Apply View

        Pixel fill
        Ignore zero values? (y,n) y
        Enter nr of lines per step: 2*2
        Clear screen? (y,n) y
        Enter color for frame: 0
        Use color information map? (y,n) y
        Enter info map name: DEM*3

*1 *As mentioned above, the perspective view can be adjusted. For the present study, the view parameters are shown. These values were adjusted manually to refine the three-dimensional view and displayed on the monochrome screen.*

*2. *This value determines the size of the gridded mesh.*

*3 *Colour information are read from Byte raster maps only. CONTOUR is an Integer raster map - containing real values upto 3 decimal places. For the purpose of displaying the digital elevation model, a corresponding Byte map - DEM was created, by simply truncating the decimal values from the Integer map CONTOUR. This means that a minimum difference of elevation of 1 meter is required for the change to be discernible.*

Figure 6.7(a): Flowchart for Generating Digital Elevation Models

- Apply View
  - Fast line grid

    Ignore zero values? (y,n) *y*
    Enter lines per step: *15*
    Clear screen? (y,n) *n**1
    Enter color for frame: *0*
    Use color information map? (y,n) *n*

*1. *The DEM remains displayed on the screen*

Figure 6.7(b): Modification of 6.7(a) for Draping Rectangular Grid on DEM

6.5 INTERACTIVE MODELLING OPERATIONS

Burrough (1986) observes that the users of GIS are not necessarily interested in knowing exactly how the various point, region and polygon operations are programmed, nor in the exact methods used for organising the data in the computer. He argues, that the user is more likely to have a good general knowledge of arithmetical and logical processes, and would prefer to use these existing skills for the geographical analyses that must be done, and ideally "would like to be able to express his thoughts in a language that is also very similar to that used in his daily work" (Burrough, 1986). Tomlin (1980, 1983), made efforts towards turning a set of computer programmes into a useful *interactive* tool-chest proposing a method for defining what he called a *map algebra*. Burrough (1986) comments that the works of researchers like Tomlin have shown that it is possible to create an unlimited number of tailor-made map-processing capabilities that can be used to tackle many analytical problems in geographical information processing.

The ILWIS package supports the performance of user-defined modelling operations. The command language used for the definition of the operations is simple and compact. This particular facility is available in the module, shown in Figure 6.8.

- RASTER
    - SPATIAL MODELLING
        - Calculation

Figure 6.8: Module for Map Calculations

This module is mostly used for the execution of spatial analysis functions and modelling operations. It integrates spatial and tabular data. The programmes enable the user to perform overlay, retrieval and neighbourhood operations. The following operations can be executed.

1) Manipulation of one or more raster maps by performing arithmetical, logical and conditional and neighbourhood operations.
2) Integration of tabular data (attributes) and raster maps.
3) Integration of two raster maps according to two-dimensional tables.
4) Classification of raster maps using classify tables.
5) Creation, storing and application of functions.

Two of the most commonly used facilities of this module are: formula execution and function definition. For the present study, both of these facilities have been used. Formula to be executed consists of an output map, containing the result of a calculation, an assignment symbol (:=) and an expression (e.g., *OUTPUT:= EXPRESSION*). The expression may consist of any combination of operands, operators and functions.

Operands specify the raster maps, tables, etc. to be used for the manipulation. Operators and functions specify the operations to be performed. The list of the standard operators are given in the ILWIS 1.4 User's Manual (1993). Another facility offered by these programmes is that the output map type can be specified. Before the execution is carried out, the output raster map type is asked for. The conversion of raster maps from the *Byte* type to the *Bit* type, as discussed in Sections 5.6.1 and 5.6.3, can be carried out.

If a specific function is often used, with different maps, constants or tables, it can be stored on the disk and called as and when it is to be executed. This is analogous to function definitions in standard high-level programming languages. In ILWIS, function definition consists of a function name, assignment symbol and an expression. The expression is made up of dummy parameters (@) followed by the parameter number (e.g., @1, @2, @3), which are substituted by the actual parameters when the function is applied. The ILWIS package itself supports a set of standard functions, the details of which are given in the User's Manual. Some of the most commonly used amongst these include the *IF* function. It can be looked upon as the integrated version of the *IF-THEN-ELSE* loop of any standard programming language. The operating syntax is readily comprehensible, and given by the following example: *output:= IF(condition, then, else)*.

In the present study, the integration of the linearly interpolated elevation information from the contour lines and the point elevation information was carried out in this module to generate the raster map ***CONTOUR*** which was used as the digital elevation model. The operation involved the following steps.

1) Superimposition of the raster map ***STCPNT*** (with point elevation information, pixels which do not represent data point are having 0 values) on the raster map ***STCONT*** (with elevation information interpolated from contour lines). In the resulting map, the pixels at locations where point information is available, is assigned that value, the rest is assigned the value of ***STCONT***. The formula is as follows:

   TRIAL1:= IF (STCPNT=0, STCONT, STCPNT)

   It is to be noted that due to discrepancy in the point data and the interpolated values, on the resulting raster map ***TRIAL1***, some of the point information yield isolated, very high or very low values, incoherent with the neighbouring pixels. As noted in the previous section, this may be due to local undulations not represented by the contour lines and consequently by the interpolated surface. However, isolated *peaks* or *gorges* in an otherwise plain land is quite an unlikely phenomenon and the change of elevation, no matter how rapid, cannot be expected to have digital discreteness. To provide for the gradual change in elevation, smoothing operations were carried out.

2) The smoothing operation is carried out by the application of a filter. The details of filters as applied to image processing can be found elsewhere (Mather, 1987; Richards, 1994). For the present purpose, filtering can be viewed as a process in which each pixel value in a raster map is replaced with a new value, which is obtained by applying a certain function to the pixel and its neighbours. For the op-

eration of smoothing, the current pixel value is replaced by the average of that pixel and its 8 (in case of a 3x3 filter) or 24 (in case of a 5x5 filter) adjacent neighbours. The ILWIS package supports standard 3x3 (*SMOOTH*) and 5x5 (*SMOOTH5*) smoothing filters. The 3x3 filter was applied on the raster map *TRIAL1* as shown in Figure 6.9.

- RASTER
  - SPATIAL MODELLING
    - Filter
      - Enter input filter name: ***SMOOTH***
        Enter input map name: ***TRIAL1***
        Enter output map name: ***SMOOTH1***

Figure 6.9: Flowchart for Executing Filters

In the filtered raster map ***SMOOTH1*** however, the pixels surrounding the isolated peaks and gorges are replaced by values intermediate between those isolated points and the surrounding plain, but it is to be noted, that the point elevation information are also replaced by the average of the pixel representing the point and its 8 neighbours. These information needs to be reinstated.

3) The raster map ***STCPNT*** is superimposed on the filtered raster map ***SMOOTH1*** in a way similar to the process mentioned in the first step above as follows:

TRIAL2:= IF (STCPNT=0, SMOOTH1, STCPNT)

These steps were carried out recursively for three iterations, at the end of which, the integrated elevation database ***CONTOUR*** was created as follows:

CONTOUR:= IF (STCPNT=0, SMOOTH3, STCPNT)

The image of this map is shown in the Appendix below (Plate A.5).

For the present study, the database containing the information about the slope of the study area terrain, was also created. This database was entirely prepared by using the neighbourhood-operation facilities offered by the ILWIS package.

Neighbourhood-operations are significantly important modelling techniques. In these operations, a window of 3x3 cells is in effect moved over the raster map(s). The neighbourhood-operator or function is applied to each cell of the input map or to the selected cell(s). Each cell of the output map is calculated according to the specified neighbourhood-operator expressions. The cells of the moving window are numbered as shown in Figure 6.10.

1	2	3
4	5	6
7	8	9

Figure 6.10: Numbering of Moving Window Cells for Neighbourhood Operations

This means, that the top neighbour of the central pixel is numbered 2, the central pixel is numbered 5 and so on. In ILWIS Calculation notation, these pixels for a particular file are referred to, by the symbols *#[2]* and *#[5]* respectively, following the filename.

The following operations were performed for building the database containing the information about the slope of the study area:

1) A function for the calculation of the elevation gradient in the *X* (East-West) direction was defined as follows:

   DX := (CONTOUR#[4] - CONTOUR#[6]) / 50

2) A function for the calculation of the elevation gradient in the *Y* (North-South) direction was defined as follows:

   DY := (CONTOUR#[2] - CONTOUR#[8]) / 50

3) A function for calculating the cosine of the slope of the terrain at a particular point with respect to the horizontal (*X-Y*) plane was defined as follows:

   SLOPE := SQRT(DX*DX + DY*DY +1)

   Where the operator ***SQRT*** finds the square root of the argument (terms within the bracket following the operator). The details and the justification of the formula used for the calculation of the cosine of the slope, are given elsewhere (Kreyszig, 1983).

(The raster maps ***DX***, ***DY*** and ***SLOPE*** were all stored as *Integer* raster maps with a scale of -3.)

The creation of the raster maps ***CONTOUR*** and its derivative ***SLOPE*** completes the process of building of database. Only the database for slope of the study area has its origin in the RASTER module. The development of all the other database were started in the VECTOR module and got their final form in the RASTER module.

7. APPLICATION OF THE ANALYTIC HIERARCHY PROCESS FOR RANKING SOLID WASTE DISPOSAL SITES

7.1 GENERAL

In the preceding chapters, the working details of the preparation of a digital database, using the tools available in a GIS environment, has been discussed in details. This chapter deals with the application of the prepared database, in the systems environment, for the identification of potential sites for solid waste disposal, and ranking the identified sites.

The site selection study for municipal solid waste disposal can be a costly affair (Joyce, 1990). Governments with limited capitals may be inclined to minimise the effort expended on site selection studies. As such, applications of GIS techniques for the purpose of landfill site selection have been reported in literature. Kao and Lin (1996), have described a technique for the selection of an optimal site based on multiple factors, including the compactness of the site, for the Yuanli County in Taiwan.

Siddiqui *et al.* (1996) also used GIS for landfill site selection for the Cleveland County of Oklahoma. The study involved the application of *Analytical Hierarchy Process*, a decision-making procedure, for the purpose of preliminary site selection. In their study, Analytic Hierarchy Process was used to rank large numbers of small land-area cells, based on cell attributes. The paper presented a review of the available landfill site selection procedures and introduced a tool called *spatial-AHP*, combining the evaluation ability of the Analytic Hierarchy Process with the analytical abilities of GIS. Three major decision factors were considered for the determination of landfill suitability, namely, hydrogeology/geology, land use and proximity to population centres, and the authors concluded that in order to make an effective use of spatial-AHP for site selection studies, digital databases containing more site attributes would be helpful.

The principal objective of the studies presented in this chapter is to illustrate the application of spatial-AHP, in the context of selecting and ranking the potential sites, for the disposal of solid wastes of Kanpur city. Before embarking upon the actual application, a brief introduction to the Analytic Hierarchy Process is given in Section 7.2.

7.2 THE ANALYTIC HIERARCHY PROCESS

The Analytic Hierarchy Process (AHP) is a methodology to systematically evaluate, often conflicting, qualitative criteria. It is a relatively new addition to the family of multi-attribute decision models and was developed by Saaty (1980). Like other multi-attribute decision models, AHP also attempts to resolve conflicts and analyse judgements through a process of determining the relative importance of a set of activities or criteria. The methodology is based on the concept of *trade-off* and enables the decision-maker to develop the trade-off implicitly in the course of structuring and analysing a series of reciprocal pair-wise comparison matrices.

The AHP can be succinctly summarised in terms of its three principal components. First, the principal problem is decomposed into a hierarchy. Each level of hierarchy consists of a set of elements and each element, in turn, is broken into sub-elements for the next level of the hierarchy. The final level consists of the specific courses of action that are being contemplated for adoption. Structuring any problem hierarchically is an efficient and intuitive way of dealing with the complexity and identifying the relevant components of the problem (Srinivasan and Kim, 1989).

Second, within each hierarchical level, relative weights for the various elements are established using a measurement methodology. Use of the methodology requires the decision-maker to evaluate the elements in a particular level in a pair-wise fashion using a 9-point scale shown in Table 7.1. The pair-wise comparisons indicate the degree to which one element dominates another element of the same level, with respect to each element of the preceding level.

Third, the pair-wise comparison matrices are evaluated using a measurement theory. The basic assumption underlying the measurement theory in the AHP is that relative dominance can be measured by pair-wise comparisons. A pair-wise comparison of a set of n attributes can be conducted and their relative importance can be established as follows:
If the attributes are denoted by $O_1, O_2, \ldots, O_n$ and their relative importance by $w_1, w_2, \ldots, w_n$, the pair-wise comparison matrix O may be expressed by the reciprocal matrix as shown below.

$$
O = \begin{array}{c|cccc}
 & O_1 & O_2 & \cdots & O_n \\
\hline
O_1 & w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\
O_2 & w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\
\cdot & \cdot & \cdot & \cdots & \cdot \\
O_n & w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n
\end{array}
$$

where, w_i/w_j reflects the relative importance of element i over element j. If O is multiplied by the transpose of the vector, $w^T \equiv (w_1, w_2, ..., w_n)$, we obtain the vector nw and the problem takes the form:

$$Ow = nw \qquad [7.1]$$

It is implicitly assumed, in the case above, that the weights, w, are known. In case only O is known and the weights are to be recovered, the system $(O-nI)w = 0$, needs to be solved for the unknown w. This has a non-zero solution if and only if n is an eigenvalue of O, i.e., it is a root of the characteristic equation of O. But O has unit rank since every row of O is a constant multiple of the first row. Thus, all the eigenvalues, λ_i, $i = 1, 2, ..., n$, of O are 0 except one (Kreyszig, 1983). It is also known that

$$\sum_{i=1}^{n} \lambda_i = \text{trace}(O) \equiv \text{sum of the diagonal elements} = n$$

Therefore, only one of the λ_i, λ_{max} (the maximum eigenvalue), equals n and all the other $\lambda_i = 0$. The solution w of the above eigenvalue problem is any column of O. These solutions differ by a multiplicative constant. However, for operational reasons, it is desirable to normalise the solution so that the weights sum to unity. The result is a unique solution regardless of which column is used.

The matrix O satisfies the *cardinal consistency* property $O_{ij}.O_{jk} = O_{ik}$. Thus, given any row of O, the rest of the entries can be determined from this relation. However, the scale w is unknown and thus, only the estimates of the ratios in the matrix can be made. In this case, the cardinal consistency relation need not hold, nor need an *ordinal transitivity* relation of the form: $O_i>O_j \cap O_j>O_k \Rightarrow O_i>O_k$ (where, O_i are the rows of O). Since qualitative judgement remains inconsistent and intransitive, despite best efforts, the inconsistency in the comparison data needs to be considered. It can be shown in any matrix, that small changes in the coefficients implies small changes in the eigenvalues. It is also known, from the Perron-Frobenius theorem, that a matrix of positive elements has a real positive eigenvalue whose modulus exceeds those of all other eigenvalues (Encyclopaedia of Mathematics, 1985). The problem $Ow = nw$, can thus be transformed to $O'w' = \lambda_{max}w'$, where, O' represents the matrix, which does not satisfy the cardinal consistency property; λ_{max}, the maximum eigenvalue of matrix O', and w' the eigenvectors, corresponding to λ_{max}. The corresponding eigenvector solution is unique when normalised.

The question that comes up then is how close, in such cases, is λ_{max} to n and w' to w. Saaty (1980) has shown that for all possible states and that $(\lambda_{max}-n)/(n-1)$ serves as an index measure of consistency. The index indicates the departure from consistency of the comparison ratio, w_i/w_j, and the ratios are deemed consistent, if $\lambda_{max} = n$. Saaty (1986) has established, for different order random entry reciprocal matrices, an average consistency index which ranges from 0 for 1 to 2 element matrices, to 0.9 for 4 element matrices and 1.49 for 10 element matrices.

Thus, the pair-wise comparison matrix O is used to elicit the judgement of decision-makers or a group of experts with regards to the relative importance of a set of attrib-

utes for each element of the preceding level. The principle eigenvector (corresponding to the maximum eigenvalue) is then extracted and normalised to yield local priorities for the elements of the matrix. Several methods can be used for deriving priority vectors from pair-wise reciprocal comparison matrices. Fichtner (1986) carried out a comparative analysis of the various methods. Saaty (1980) advocates the use of the principle eigenvector method. The method proposed by Saaty (1980) for the calculation of the eigenvector elements is given in Section 7.3.3. Local priorities are then transformed to global priorities by weighting them with the global priorities of the elements of the preceding level. Continuing this process of eigenvector extraction and weighting through the levels of the hierarchy leads to a uni-dimensional priority (weight) scale for the elements in the final level. An illustration of this process is given by Srinivasan and Kim (1989). For the present study, this process was applied, the details of which are given in Section 7.3.3.

7.3 INTEGRATION OF AHP WITH THE GIS DATABASE

For the present study, the spatial-AHP technique, developed by Siddiqui *et al.* (1996), was applied to identify and rank potential sites for solid waste disposal. The AHP decision making method, as used in spatial-AHP involves the following five steps (Siddiqui *et al.*, 1996): (1) identifying the decision factors associated with the problem; (2) structuring them in a decision hierarchy; (3) judging the relative importance of the decision-hierarchy elements; (4) aggregating these measures in order to calculate a suitability index of the alternatives; and (5) ranking the raster elements (pixels) according to the suitability indices. In the present study, following step 4, the regions restricted by legal jurisdictions, physical obstructions, etc., were eliminated from the ranking operation. These steps are described subsequently.

7.3.1 Decision Factors

Decision factors are used to relate attributes to suitability concerning a particular goal, as in this case, selecting potential sites for solid waste disposal. First, the major decision factors are identified. As discussed in Chapter 3, the primary factors which contribute significantly to the site selection criteria include the terrain information, information about the hydrogeological/geological parameters, land use/land cover information, the economic viability of the proposed site and factors based on legal, social, environmental or political restrictions and physical feasibility (presence of water bodies, proximity to roads, etc.).

For the present study, the land use/land cover information was not available. The decision factors comprised of terrain information, hydrogeological/geological factors, factors ensuring environmental acceptability, physical feasibility and political restrictions. These factors were classified under two groups, namely, the *exclusionary* criteria, including the factors based on physical feasibility and political restrictions and the *non-exclusionary* criteria, consisting of the remaining decision factors.

Table 7.1: Analytic Hierarchy Measurement Scale (Srinivasan and Kim, 1989)

Reciprocal Measure of Intensity of Importance	*Definition*	*Explanation*
• 1	Equal importance	*Two activities contribute equally to the objective*
• 3	Weak importance of one over another	*Experience and judgement slightly favour one activity over another*
• 5	Essential or strong importance	*Experience and judgement strongly favour one activity over another*
• 7	Demonstrated importance	*An activity is strongly favoured and its dominance is demonstrated in practice*
• 9	Absolute importance	*The evidence favouring one activity over another is of the highest possible order of affirmation*
• 2, 4, 6, 8	Intermediate values between two adjacent judgements	*When compromise is needed*
• Reciprocal of the above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*.	

The study area, as mentioned in Section 5.2, includes three neighbouring districts, namely, Kanpur Dehat, Kanpur Nagar and Unnao. Thus for the selection of a site for the disposal of solid wastes of the Kanpur city (which is the Kanpur Nagar district), the other two districts were left out of consideration. Similarly regions in the study area which are limited by physical restrictions, for instance ponds, streams, rivers and other water bodies with surface water, were also excluded. Pixels representing road and rail networks were excluded from consideration, for obvious reasons. These three considerations essentially constitute the exclusionary criteria that were incorporated in the present study. The application of the exclusionary criteria involves a simple modelling operation in the GIS environment (Section 7.3.4).

The non exclusionary criteria are the ones for which the pair-wise comparison of AHP is applicable. Once the non-exclusionary decision criteria are selected, sub-factors and

even sub-sub-factors are identified to better describe these criteria. For instance, terrain information can be categorised into information about the *elevation* above the mean sea-level and the *slope*. The information about elevation can be further grouped within selected class-intervals based on the elevation values.

7.3.2 Decision Hierarchy

The non-exclusionary decision factors, after being identified are arranged in a decision hierarchy. A decision hierarchy consists of a number of levels. The top level is the goal of the hierarchy, while the rest of the levels describe the factors and the sub-factors in increasing details. The lowest level contains the attributes of each alternative site. The construction of these levels are qualitative and depends on the decision-maker's understanding of the problem.

For the present study, the decision hierarchy used, is given in the schematic diagram in Figure 7.1. The range of values, that were used for some of the Level IV parameters, are based on judgement. Any other justified range of values can be used.

Other reasonable decision hierarchy can be incorporated within the same framework. For example, other decision factors can be used, depending on the decision-maker's perspective. Data availability, of course, is an important pre-requisite. Each factor used in the decision hierarchy must have appropriate data for the entire study area under investigation in a format that can be incorporated into the GIS. Decision hierarchies used in the present study uses data that were readily available. Because some other data of significant importance, for the selection and ranking of potential sites for solid waste disposal were not available for the present study, the results do not represent the final evaluation step in the site selection procedure. Rather it can be said that the results serve the purpose of *preliminary site selection based on the selected decision factors*.

7.3.3 Relative Importance Weights and Suitability Index

The *Suitability Index* for each cell is determined by aggregating the *Relative Importance Weight* (RIWs) at each level of the hierarchy (Siddiqui *et al.*, 1996). The RIWs are the normalised eigenvectors corresponding to the maximum eigenvalues of the pair-wise comparison matrices constructed at each level of the decision hierarchy. The RIW assigned to each hierarchy element is determined by normalising the eigenvector of the decision matrix (Tables 7.2-7.11[1]). Eigenvector values are estimated by multiplying all the elements in a row and taking the nth root of the product, where n is the number of row elements (Saaty, 1980). For example, for the first row in Table 7.2, where n is 3 the eigenvector value is given by $\sqrt[3]{1.6.8}$, or 3.634. Normalisation of the eigenvector is accomplished by dividing each eigenvector element by the sum of the eigenvector elements of the decision matrix. For the first row in Table 7.2, the RIW is given by 3.634/(3.634+1.000+0.275), or 0.740.

[1] For convenience and clarity, Tables 7.2-7.11 are presented at the end of this chapter.

The calculation of the RIWs are shown in Tables 7.2-7.11 where the weights are calculated for the different levels (levels II, III and IV) of the decision hierarchy. The numbers used in the decision matrices (shown in the tables), signifying the relative importance of the compared elements, are also based on judgement, like the range of values used for some of the Level IV parameters shown in Figure 7.1.

Level I	Level II	Level III	Level IV
Suitable Site for Solid Waste Disposal	Terrain Characteristics	*Slope*	*0-<10°* *≥10°*
		Elevation above msl (in Mts.)	*110-<113* *≥113-<118* *≥118-<125* *≥125*
	Hydrogeological/Geological Characteristics	*Depth of Water Table (in Mts.)*	*≥11* *≥9-<11* *≥7-<9* *<7*
		Surface Soil Type	*Aridisols* *Alfisols* *Entisols*
	Environmental Considerations	*Distance from Road/ Rail Networks (in Mts.)*	*≥100* *<100*
		Distance from Water-bodies (in Mts.)	*≥500* *≥150-<500* *≥50-<150* *<50*

Figure 7.1: Schematic Diagram of Decision Hierarchy

The Suitability Indices based on the non-exclusionary parameters are calculated by multiplying the RIWs of a cell's attribute value(s) by the RIW of the associated higher level factors, summing the values for all grouped elements, multiplying those sums by the RIWs of the associated higher level factor, and following this process recursively until the primary non-exclusionary decision factors (level 2, in the hierarchy) are reached. For the four level hierarchy, as in the present study, the equation is as follows.

$$NSI = \sum_{i=1}^{N2} \left[RIW_i^2 . \sum_{j=1}^{N3_i} \{ RIW_{i,j}^3 . (RIW_{i,j,k}^4) \} \right] \qquad [7.2]$$

where, *NSI* = Non-exclusionary Suitability Index; *N*2 = Number of non-exclusionary decision factors in level 2; RIW^2_i = Relative Importance Weight of level 2 decision factor *i*; $N3_i$ = Number of level 3 sub-factors directly connected with level 2 decision factor *i*; $RIW^3_{i,j}$ = Relative Importance Weight of level 3 sub factor *j* of level 2 decision factor *i*; and $RIW^4_{i,j,k}$ = Relative Importance Weight of level 4 attribute category *k* of level 3 sub factor *j* and level 2 decision factor *i*. If decision factor *i* has no level 3 sub-factors, $N3_i$ = 1 and $RIW^3_{i,1}$ = 1. In case a decision has more or fewer levels, modification of Equation 7.2 can be made appropriately. An example to illustrate the use of the equation is given elsewhere (Siddiqui *et al.* 1996).

Suitability Indices using Equation 7.2 for all the raster cells were simultaneously determined by using the GIS map algebra (The *Calculation* subprogram of the RASTER module of the ILWIS package). The higher the suitability number for a given cell, the more suited the cell is to become a part of a prospective site. For the creation of the map representing the suitability for disposal based on the non-exclusionary decision factors, the following equation was executed.

NSI:=0.056(0.857*(RIW11)+0.143*(RIW12))+0.204*(0.125*(RIW21)+0.875*(RIW22)) + 0.740*(0.111*(RIW31+RIW32)+0.889*(RIW33))*

where, ***NSI*** is the raster map containing the Suitability Index based on the non-exclusionary criteria, the numbers are the RIWs of the Level II and Level III decision factors, obtained from the Tables 7.2, 7.3, 7.6 and 7.9 and ***RIW11***, ***RIW12***, etc., are the raster maps, containing the Level IV RIWs based on the pixel values of the various maps stored in the GIS database.

The raster map containing the Suitability Index values (*SI*), incorporating the non-exclusionary as well as the exclusionary decision factors, was made by executing the following equation.

*SI:=NSI*REGION*WBPOLY*STROADS*STRAILS*

where, ***REGION***, ***WBPOLY***, ***STROADS*** and ***STRAILS*** are the *Bit* raster maps containing information about the political boundaries (pixels representing Kanpur Dehat and Unnao districts, having value 0 and pixels representing areas within the Kanpur Nagar district, having value 1, as described by the flowchart shown in Figure 5.7), extent of the water bodies (as discussed in Section 5.6.3) and the layout of the road and rail networks in the study area respectively (as discussed in Section 5.6.1). Multiplication of *NSI* with these maps effectively implies the incorporation of the exclusionary criteria.

7.3.4 Suitability Ranking

After calculating the Suitability Index of each raster element (pixel), threshold values were selected for the purpose of classifying the pixels into groups and for subsequent ranking. For the present study, four ranks were used, with rank 1 implying the best

suitability. The histogram of the Suitability Index values were calculated and the selection of the thresholds were based on the histogram.

The pixel values in the raster map *SI*, were clustered within specific ranges of Suitability Index values, and consequently, the histogram demonstrated isolated peaks in those ranges. The top four classes were isolated, and were used for ranking. The histogram of these are shown in Figure 7.2

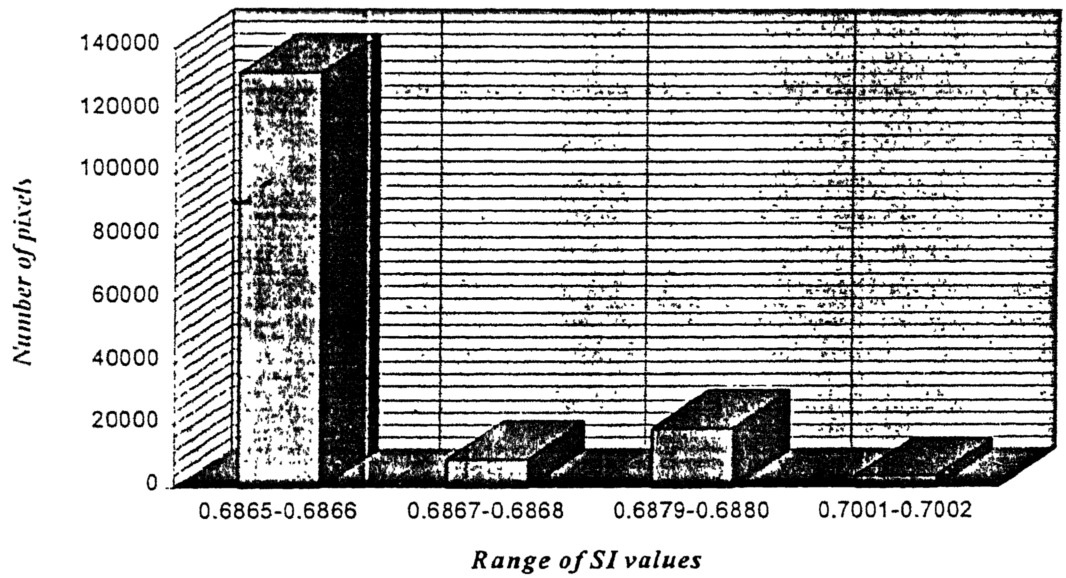

Figure 7.2: Histogram of the Suitability Index Values in Raster Map SI

Pixels in the raster map *SI* having values in the ranges shown in Figure 7.2 were orderly assigned ranks from 1 through 4, with rank 1 being assigned to pixels having the index value between 0.7001 to 0.7002; rank 2, for pixel values between 0.6879 and 0.6880, etc. Following the assignment of ranks the resultant map ***RANK***, provided the preliminary ranks indicating the suitability of each of the raster elements for solid waste disposal. The image of the map is presented in Plate A.6.

7.4 CONCLUDING REMARKS

In view of the discussion, presented in Section 4.6, the authenticity of the various databases prepared and accuracy of the final output of the site selection operation, or at least the sources of errors, can be estimated. Data availability and the quality of data remains the limiting factors in any database-dependant modelling operation, and as mentioned above, are the possible sources of inherent errors. The quality of some of the data, available for the present study were reasonably good. The Survey of India topography sheets at 1:25,000 scale, used for the present study, provide the information about the elevation above the mean sea-level at the smallest scale. Moreover, information from bench marks and triangulated heights were also incorporated in the elevation database. The rail and the road networks too, were digitised from the same maps. Hence, these information are expected to be reasonably accurate as well.

The data of the surface soil type, derived from the NATMO maps, were available at 1:500,000 scale. Consequently a compromise in the quality of information can be expected. As such, only three classes of soil could be discerned.

The water table data, available for the study, were of coarse details. Log data were available for different sampling points, at different parts of the study area. The exact location of the sampling stations however, were not available. Only the information about the locality in which the stations were located, was available. These locations were identified on the Survey of India maps, and were used for the input of water table data. For each of these locations, multi-temporal water table data were available. In the context of disposal site selection, the post-monsoon water table depths (when the water table is expected to be nearest to the ground level) were used. This ensures a conservative modelling.

The information about the slope derived from the elevation database and the distance from the roads and rail networks may suffer from operational errors. The accuracy of any raster modelling, in general, depends largely on the spatial resolution or the scale of the operation. For the present study, a resolution of 25 metres was adopted. The accuracy of the results of spatial modelling also depends on the accuracy of the source database from which the model derives its basic data. Hence, the root of operational errors ultimately stems from the accuracy of the process of data input, i.e., the operation of manual digitisation.

The accuracy of the final modelling, integrating the GIS database with the AHP, depends on the quality of the database and on the fundamental assumptions of the AHP technique. The construction of the decision matrices (Tables 7.2-7.11), largely determines the final output, but as mentioned in Section 7.3, the construction of these matrices are essentially subjective, as is any other decision-making process, based on judgement.

Table 7.2 : Level II Relative Importance Weights Non-Exclusionary Criteria (λ_{max}=3.257)

Level II Parameters → ↓	Environmental Considerations	Hydrogeology/ Geology	Terrain	Estimated Eigen Element	RIW
Environmental Considerations	1	6	8	3.634	0.740
Hydrogeology/Geology	1/6	1	6	1.000	0.204
Terrain	1/8	1/6	1	0.275	0.056

Table 7.3: Level III Relative Importance Weights for Slope and Elevation of Terrain (λ_{max}=2.000)

Level III Parameters → ↓	Slope	Elevation	Estimated Eigen Element	RIW
Slope	1	6	2.449	0.857
Elevation	1/6	1	0.408	0.143

Table 7.4: Level IV Relative Importance Weights for Slope of Terrain in degrees (λ_{max}=2.000)

Level IV Parameters → ↓	0-<10°	≥10°	Estimated Eigen Element	RIW
0-<10°	1	5	2.236	0.833
≥10°	1/5	1	0.447	0.167

Table 7.5: Level IV Relative Importance Weights for Elevation above Mean Sea-Level in meters (λ_{max}=4.517)

Level IV Parameters → ↓	110-<113	≥113-<118	≥118-<125	≥125	Estimated Eigen Element	RIW
110-<113	1	5	7	9	4.212	0.621
≥113-<118	1/5	1	6	8	1.760	0.259
≥118-<125	1/7	1/6	1	5	0.587	0.086
≥125	1/9	1/8	1/5	1	0.229	0.038

Table 7.6: Level III Relative Importance Weights for Water Table and Soil (λ_{max}=1.999)

Level III Parameters → ↓	Water Table	Soil	Estimated Eigen Element	RIW
Water Table	1	7	2.646	0.875
Soil	1/7	1	0.378	0.125

Table 7.7: Level IV Relative Importance Weights for Depth of Water Table below Ground Level in meters (λ_{max}=4.239)

Level IV Parameters → ↓	≥11	≥9-11	≥7-<9	<7	Estimated Eigen Element	RIW
≥11	1	3	5	9	3.049	0.564
≥9-<11	1/3	1	4	6	1.682	0.278
≥7-<9	1/5	1/4	1	5	0.707	0.117
<7	1/9	1/6	1/5	1	0.247	0.041

Table 7.8: Level IV Relative Importance Weights for Surface Soil Types (λ_{max}=3.269)

Level IV Parameters → ↓	Aridisols	Alfisols	Entisols	Estimated Eigen Element	RIW
Aridisols	1	6	9	3.780	0.744
Alfisols	1/6	1	7	1.053	0.207
Entisols	1/9	1/7	1	0.251	0.049

Table 7.9: Level III Relative Importance Weights for Distance from Water Bodies and Road/Rail Networks in metres (λ_{max}=2.000)

Level III Parameters → ↓	Water Bodies	Roads/Rails	Estimated Eigen Element	RIW
Water Bodies	1	8	2.828	0.889
Roads/Rails	1/8	1	0.354	0.111

Table 7.10: Level IV Relative Importance Weights for Distance from Water Bodies in meters (λ_{max}=4.506)

Level IV Parameters → ↓	≥500	≥150-<500	≥50-150	<50	Estimated Eigen Element	RIW
≥500	1	4	7	9	3.984	0.596
≥150-<500	1/4	1	6	8	1.861	0.279
≥50-<150	1/7	1/6	1	6	0.615	0.092
<50	1/9	1/8	1/6	1	0.219	0.033

Table 7.11: Level IV Relative Importance Weights for Distance from Road and Rail Networks in metres (λ_{max}=1.999)

Level IV Parameters → ↓	≥100	<100	Estimated Eigen Element	RIW
≥100	1	9	3.000	0.900
<100	1/9	1	0.333	0.100

8. EPILOGUE

This thesis presents an elaborate introduction to GIS, along with the operational details of building a database in a GIS environment. These details however, have been furnished in the context of the ILWIS package, but the basic structure and the sequence of operations mentioned, hold true for other GIS packages as well. This study also illustrates, how the capabilities of GIS can be utilised for addressing problems of spatial nature, with the efficiency of handling large volumes of spatial data, and with speed, which is quite typical of computer-based operations.

One other objective of the study, was preliminary site selection for solid waste disposal, based on some decision factors. The choice of the decision factors, were guided predominantly by the availability of data. In the process of the site selection study, a comprehensive description of AHP has been provided along with the records of the application of AHP for landfill siting. The present study was an attempt, in a similar direction, to preliminary site selection for open dumping of solid wastes of Kanpur city. The gap between the preliminary and the final stage of site selection can be laid down as the scope for future work.

One vital database, relevant to the site selection process, that could not be incorporated in the present study, is the land use/land cover information. With the availability of this information, not only can the present land use patterns in the study area be estimated, but the status and potential of the existing disposal sites can also be evaluated. This information is currently available with the Town and Country Planning authorities of Kanpur city, but it can also be derived directly from remotely sensed satellite images. One advantage of using satellite images is that the networks of the roads and rails, digitised from the topography sheets, can be verified. Feature extraction techniques of image processing can be applied on the satellite images to yield information about saline patches and other waste lands in the study area as well. This can assist in identifying future prospective sites for solid waste disposal.

Another important task, is the digitisation of the waste collection points in the study area. This information, is available with the Northern Zonal Office of the Central Pollution Control Board, in Kanpur. This information along with the data of the distance of the potential sites from these locations can serve as an essential database. The cost of the waste disposal practice depends substantially on the distance of haul of the waste collection vehicles. Integrating the haul distance into the database, can help to find the optimal route(s) to the disposal site(s). The calculation of these distances is supported in the VECTOR module of the ILWIS package. The pre-requisite of this operation is that the individual road segments have to be digitised separately with a unique code distinguishing one road segment from the other.

These operations could not be incorporated as a part of the present study, primarily due to lack of data and the constraint of time. It is hoped that this task will be taken up in the near future so as to reach the final stage of solid waste disposal site selection for Kanpur city.

REFERENCES

1) Abler, R.F., 1987, The National Sciences Foundation Center for Geographic Information and Analysis, International Journal of Geographic Information Systems, **1**.

2) Aller, L., 1985, DRASTIC: A Standard System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings, Report No. EPA/600/2-85/018, U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Lab, Ada, Oklahoma.

3) Anderson, J.M., and E.M. Mikhail, 1985, Introduction to Surveying, McGraw-Hill, Singapore.

4) Beller, A., T. Giblin, K.V. Le, S. Litz, T.G.F. Kittel and D.S. Schimel, 1991, A Temporal GIS Prototype for Global Change Research, Proceedings, GIS/LIS '91, Atlanta, Georgia.

5) Bouillé, F., 1978, Structuring Cartographic Data and Spatial Processes with the Hypergraph-Based Data Structure, in First International Advanced Study Symposium on Topological Data Structures for Geographic Information Systems (ed. G. Dutton), **5**, Laboratory for Computer Graphics and Spatial Analysis, Harvard.

6) Burrough, P.A., 1986, Principles of Geographic Information for Land Resources Assessment, Clovendon Press, Oxford.

7) Burrough, P.A., 1980, The Development of a Landscape Information in The Netherlands, Based on a Turn-key Graphics System, Geoprocessing, **1**.

8) Calkins, H.W., 1975, Creating Large Digital Files from Mapped Data, Proceedings, UNESCO Conference on Computer Mapping of Natural Resources, Mexico City.

9) Calkins, H.W., and R.F. Tomlinson, 1977, Geographic Information Systems: Methods and Equipment for Land Use Planning, IOU Commission on Geographical Data Sensing and Processing and U.S. Geological Survey, Ottawa.

10) Castleman, K.R., 1979, Digital Image Processing, Prentice-Hall, Englewood Cliffs, New Jersey.

11) Cheng, B.H.C., R.H. Bourdeau and B.C. Pijanowski, 1996, A Regional Information System for Environmental Data Analysis, Photogrammetric Engineering and Remote Sensing, **62**(7).

12) Clarke, K.C., 1986, Advances in Geographic Information Systems, Computers, Environment and Urban Systems, **10**.

13) Committee on Earth and Environmental Sciences, 1992, Our Changing Planet: The FY 1992 Research Plan, Federal Coordinating Council on Science, Engineering and Technology, Technical Report, Office of Science and Technology Policy, Washington, D.C.

14) Committee on Global Change, 1990, Research Strategies for the United States Global Change Research Program, National Academy Press.

15) Cowen, D.J., 1988, GIS versus CAD versus DBMS: What are the Differences?, Photogrammetric Engineering and Remote Sensing, **54**(?).

16) Crawford, J.F., and P.G. Smith, 1985, Landfill Technology, Butterworths, London.

17)Dangermond, J., 1983, A Classification of Software Components Commonly Used in Geographic Information Systems, in Design and Implementation of Computer-Based Geographic Information Systems, edited by D.J. Peuquet and John O'Callaghan, IGU Commission on Geographical Data Sensing and Processing, Amherst, New York.

18)Dangermond, J., 1988, A Review of Digital Data Commonly Available and Some of the Practical Problems of Entering Them Into a GIS, Technical Papers, ACSM-ASPRS, St. Louis.

19)DATATAB II User's Guide, 1994, ALTEK Corporation, Maryland.

20)Davis, F.W., D.A. Quattrochi, M.K. Ridd, N.S-N. Lam, S.J. Walsh, J.C. Michaelsen, J. Franklin, D.A. Stow, C.J. Johannsen and C.A. Johnston, 1991, Environmental Analysis Using Integrated GIS and Remotely Sensed Data: Some Research Needs and Priorities, Photogrammetric Engineering and Remote Sensing, **57**(6).

21)Davis, J.C., 1986, Statistics, and Data Analysis in Geology, 2nd edition, John Wiley and Sons, New York.

22)Davis, J.R., P.A. Whigham and I.W. Grant, 1988, Representing and Applying Knowledge about Spatial Processes in Environmental Management, AI applications in Natural Resource Management, **2**(4).

23)Duda, R., and P. Hart, 1973, Pattern Classification and Scene Analysis, Wiley, New York.

24)Dueker, K.J., 1979, Land Resource Information Systems: A Review of Fifteen Years Experience, Geo-Processing, **1**.

25)Encyclopaedia of Mathematics, 1985, Kluwer Academic Publishers, London.

26)ESRI, 1990, Understanding GIS - the ARC/INFO Method, Environmental Systems Research Institute, Redlands, California.

27)Estes, J.E., K.E. McGwire, G.E. Fletcher and T.W. Foresman, 1987, Coordinating hazardous waste management activities using GIS, International Journal of Geographical Information Systems, **1**.

28)Fichtner, J., 1986, On Deriving Priority Vectors from Matrices of Pairwise Comparison, Socio-Economic Planning Sciences, **20**(6).

29)Ghosh, R., R.K. Goel, B.S. Lole, T.P. Singh, K.L.N. Sastry, J.G. Patel, Y.V. Vanikar, P.S. Thakker and R.R. Navalgund, 1993, District level planning –a case study for the Panchmahals district using remote sensing and Geographic Information System techniques, International Journal of Remote Sensing, **14**(17).

30)Goodchild, M.F., 1985, Geographic information systems in undergraduate geography: A contemporary dilemma, The Operational Geographer, **8**.

31)Greene, R.G., and J.F. Cruise, 1996, Development of a Geographic Information System for Urban Watershed Analysis, Photogrammetric Engineering and Remote Sensing, **62**(7).

32)Harris, P.M., K. Kim, S.J. Ventura, T.G. Thum and J. Prey, 1991, Linking a GIS within Urban Nonpoint Source Pollution Models, Annual Proceedings, LIS/GIS, American society for Photogrammetry and Remote Sensing, Atlanta, Georgia.

33)ILWIS 1.4 User's Manual, 1993, 1st edition, ITC, The Netherlands.

34)Jensen, J.R., Christensen, E.J., 1986, Solid and Hazardous Waste Disposal Site Selection using Digital Geographic Information System Techniques, The Science of the Environment, **56**.

35)Jensen, J.R., E.W. Ramsey, J.M. Holmes, J.E. Michel, B. Savitsky and B.A. Davis, 1990, Environmental Sensitivity Index (ESI) Mapping for Oil Spills Using Remote

Sensing and Geographic Information System Technology, International Journal of Geographical Information Systems, **4**.

36)Joyce, L.E., 1990, How to Calculate Waste Disposal Costs, Government Finance Rev., **36**(3).

37)Kao, J. and H.Y. Lin, 1996, Multifactor Spatial Analysis for Landfill Siting, Journal of Environmental Engineering, ASCE, **122**(10).

38)Kineman, J.J., D.A. Hastings and J.D. Colby, 1986, Development in global databases for the environmental sciences: discussion and review, Proceedings, 12th International Symposium on Remote Sensing of the Environment, **2**, Environmental Research Institute of Michigan, Ann Arbor.

39)Kim, K., and S. Ventura, 1993a, Large-Scale Modeling of Nonpoint Source Pollution Using a Geographic Information System, Photogrammetric Engineering and Remote Sensing, **59**(10).

40)Kim, K., and S.Ventura, 1993b, Urban Nonpoint Source Pollution Assessment Using a Geographical Information System, Journal of Environmental Management.

41)Kreyszig, E., 1983, Advanced Engineering Mathematics, 5th edition, Wiley Eastern Limited, New Delhi.

42)Lyon, J.G., 1987, Use of Maps, Aerial Photographs, and other Remote Sensor Data for Practical Evaluations of Hazardous Waste Sites, Photogrammetric Engineering and Remote Sensing, **53**(5).

43)Maffini, G, 1987, Raster versus Vector Data Encoding and Handling: A Commentary, Photogrammetric Engineering and Remote Sensing, **53**(10).

44)Maguire, D.J., M.F. Goodchild and D.W. Rhind (ed), (1991), Geographical Information Systems: Principles and Applications, Longman, London.

45)Manual for Preparation of Zonal Atlas for Siting of Industries, 1995, Central Pollution Control Board, New Delhi.

46)Marble, D.F., 1984, Geographic Information Systems: an overview, Proceedings, Percora 9 Conference, Sioux Falls, S.D.

47)Marble, D.F. and D.J. Peuquet, 1983, Geographic Information Systems and Remote Sensing, Manual of Remote Sensing, 2nd edition, American Society of Photogrammetry, Falls Church, Virginia.

48)Marble, D.F. and D.J. Peuquet (ed.), 1990, Introductory readings in Geographic Information Systems, Taylor & Francis, London.

49)Mason, D.C., and J.R.G. Townshend, 1988, Research related to geographical information systems at the Natural Environment Research Council's Unit for Thematic Information System, International Journal of Geographical Information Systems, **2**.

50)Mather, P.M., 1987, Computer Processing of Remotely Sensed Images – An Introduction, John Wiley, Chichester.

51)Matheron, G., 1971, The theory of regionalized variables and its applications, *Les Cahiers du centre de morphologie mathematique de Fontainebleu,* Ecole Nationale Superieure des Mines de Paris. (Cited in Reference No. 6)

52)McLaughlin, J.D., 1984, The multipurpose cadastre concept: current status, future prospects, Seminar on the Multipurpose Cadastre: Modernization of Land Information Systems in North America, University of Wisconsin Institute of Environmental Studies, Madison.

53)Mead, D.A., 1982, Assessing Data quality in Geographic Information Systems. Remote Sensing for Resource Management, Soil Conservation Society for America, Ankeny, Iowa.

54)Mooneyhan, D.W., 1988, Applications of Geographical Information Systems within the United Nations Environmental Programme, Building Databases for Global Science, Taylor & Francis, London.

55)Nag, P., 1987, A proposed base for a Geographical Information System for India. International Journal of Geographical Information Systems, **1**(2).

56)Newcomer, J.A. and J. Szajgin, 1984, Accumulation of Thematic Map Error in Digital Overlay Analysis, American Cartographer, **11**(1).

57)Novaline Jaga, R.M., A. Sundaram and T. Natarajan, 1993, Wasteland development using Geographic Information System techniques, International Journal of Remote Sensing, **14**(17).

58)O'Callaghan, J.F., and R.D. Graetz, 1981, Software for image-based information systems: its application to integrating LANDSAT imagery and land tenure data for rangeland management, in Information systems for soil and related data, edited by A.W. Moore, B.G. Cook and L.G. Lynch, Proceedings, 2nd Australian Meeting of the ISSS Working Group on Soil Information System, Canberra, Australia.

59)Palvidis, M.G., 1982, Database management for geographic information systems. Proceedings, National Conference on Energy Resource Management, **1**.

60)Pathan, S.K., S.V.C. Sastry, P.S. Dhinwa, M. Rao, K.L. Majumdar, D. Sampat Kumar, V.N. Patkar and V.N. Phatak, 1993, Urban growth trend analysis using GIS techniques - a case study of the Bombay metropolitan region, International Journal of Remote Sensing, **14**(17).

61)Perera, L.K. and R. Tateishi, 1995, Do remote sensing and GIS have a practical applicability in developing countries? (Including some Sri Lankan experiences), International Journal of Remote Sensing, **16**(1).

62)Peuquet, D.J., 1984, A conceptual framework and comparison of spatial data models, Cartographica, **2**.

63)Peuquet, D.J. and D.F. Marble (ed.), 1990, Introductory Readings in Geographic Information Systems, Taylor & Francis, London.

64)Poiker, T.K. and N. Chrisman, 1975, Cartographic data structures, American Cartographer, **2**(1).

65)Poiker, T.K., 1985, Geographic information systems in the geographic curriculum. The Operational Geographer, **8**.

66)Pope, P., E.V. Eeckhout and C. Rofer, 1996, Waste Site Characterisation through Digital Analysis of Historical Aerial Photographs, Photogrammetric Engineering and Remote Sensing, **62**(12).

67)Populus, J., F. Moreau, D. Coquelet and J.P. Xavier, 1995, An assessment of environmental sensitivity to marine pollution: solutions with remote sensing and Geographical Information Systems (GIS), International Journal of Remote Sensing, **16**(1).

68)Prey, J.P., S.J. Ventura and K. Kim, 1993, Storm Water Pollution Control Practices Siting and Retrofitting Within the Context of a GIS, Proceedings, GIS '93, Vancouver, B.C.

69)Rampal, K.K., 1985, Textbook of Photogrammetry, Oxford & IBH Publishers, New Delhi.

70)Report of Committee on Urban Waste, 1975, Ministry of Works and Housing, Government of India.

71)Rhind, D.W., B.K. Wyatt, D.J. Briggs and J.C. Wiggins, 1986, The creation of an environmental system for the European Community, *Nachrichten aus dem Karten und Vermessungswesen*, 44(2). (Cited in Reference No. 63)

72)Richards, J.A., 1994, Remote Sensing Digital Image Analysis, Springer-Verlag, New York.

73)Robinson, G., and M. Jackson, 1985, Expert Systems in Map Design, Proceedings of Auto-Carto VII.

74)Saaty, T.L., 1980, The Analytic Hierarchy Process, McGraw-Hill, New York.

75)Saaty, T.L., 1986, Axiomatic Foundations of the Analytic Hierarchy Process, Management Science, July.

76)Sharma, S.K. and D. Anjaneyulu, 1993, Application of remote sensing and GIS in water resource management, International Journal of Remote Sensing, **14**(17).

77)Siddiqui, M.Z., Jess W. Everett and Baxter E. Vieux, 1996, Landfill Siting Using Geographic Information Systems: A Demonstration, Journal of Environmental Engineering, ASCE, **122**(6).

78)Skitt, J., 1979, Waste Disposal Management and Practice, Charles Knight & Company Limited, London.

79)Srinivasan, V. and Y.H. Kim, 1989, Financial Applications of the Analytic Hierarchy Process, Proceedings of the International Conference on Multiple Criteria Decision making: Applications in Industry and service, Asian Institute of Technology, Bangkok.

80)Stanilawski, L.V., B.A. Dewitt and R.L. Shreshtha, 1996, Estimating Positional Accuracy of Data Layers within a GIS through Error Propagation, Photogrammetric Engineering and Remote Sensing, **62**(4).

81)Stirrup, F., 1965, Public Cleansing: Refuse Disposal, Pergamon Press, Oxford.

82)Tchobanoglous, G., H. Theisen and R. Eliassen, 1977, Solid Wastes: Engineering Principles and Management Issues, McGraw-Hill, New York.

83)Theroux, P., 1985 (reprint), Sunrise with Seamonsters, Houghton Mifflin Company, Boston.

84)Tom, C., Miller, L.D., and J.W. Christenson, 1978, Spatial land use inventory, modelling and projection, Denver metropolitan area, Technical memo. N.79710, National Aeronautics and Space Administration, NSTL station, Mississippi.

85)Tomlin, C.D., 1980, Map Analysis Package (draft manual), Yale School of Forestry and Environmental Studies, Connecticut.

86)Tomlin, C.D., 1983, Digital cartographic modelling techniques in environmental planning, Ph.D. dissertation, Yale University, Connecticut.

87)Tomlin, C.D. and J.K. Berry, 1979, A mathematical structure for cartographic modelling in environmental analysis, Proceedings, 39th Symposium of the American Conference on Surveying and Mapping.

88)Tomlinson, R.F. (ed.), 1970, Environmental Information Systems, Commission on Geographical Data Sensing and Processing, International Geographical Union, Ottawa, Canada.

89)Tomlinson, R.F. (ed.), 1972, Geographical Data Handling (two volumes). UNESCO/IGU Second Symposium on Geographical Information Systems, IGU Commission on Geographical Data Sensing and Processing, Ottawa, Canada.

90)Tomlinson, R.F., and A.R. Boyle, 1981, The state of development of systems for handling national resources inventory data, Cartographica, **18**.

91)Townshend, J.R.G., 1991, Environmental databases and GIS, Geographical Information Systems: principles and applications, **2**, Longman, London.

92)Ventura, S.J. and K. Kim, 1993, Modelling Urban Nonpoint Source Pollution with a Geographic Information System, Water Resources Bulletin, **29**(2).

93)Vitek, J.D., S.J. Walsh and M.S. Gregory, 1984, Accuracy in Geographic Information Systems: An Assessment of Inherent and Operational errors, Proceedings, PECORA IX Symposium.

94)Walsh, S.J., D.R. Lightfoot and D.R. Butler, 1987, Recognition and Assessment of Error in Geographic Information Systems, Photogrammetric Engineering and Remote Sensing, **53**(10).

95)Weber, W., 1978, Three types of map data structures, their ANDs and NOTs, and a possible OR, Harvard papers on geographic information systems, First International Advanced Study Symposium on Topological Data Structures for Geographic Information Systems (ed. G. Dutton), Laboratory for Computer Graphics and Spatial Analysis, Graduate School of Design, Harvard.

96)Wheeler, D.J., 1993, Commentary: Linking Environmental Models with Geographic Information Systems for Global Change Research, Photogrammetric Engineering and Remote Sensing, **59**(?).

97)Yeh, A.G.O., 1991, The Development and Application of Geographic Information System for Urban and Regional Planning in the Developing Countries, International Journal of Geographical Information Systems, **5**.

APPENDIX: PLATES

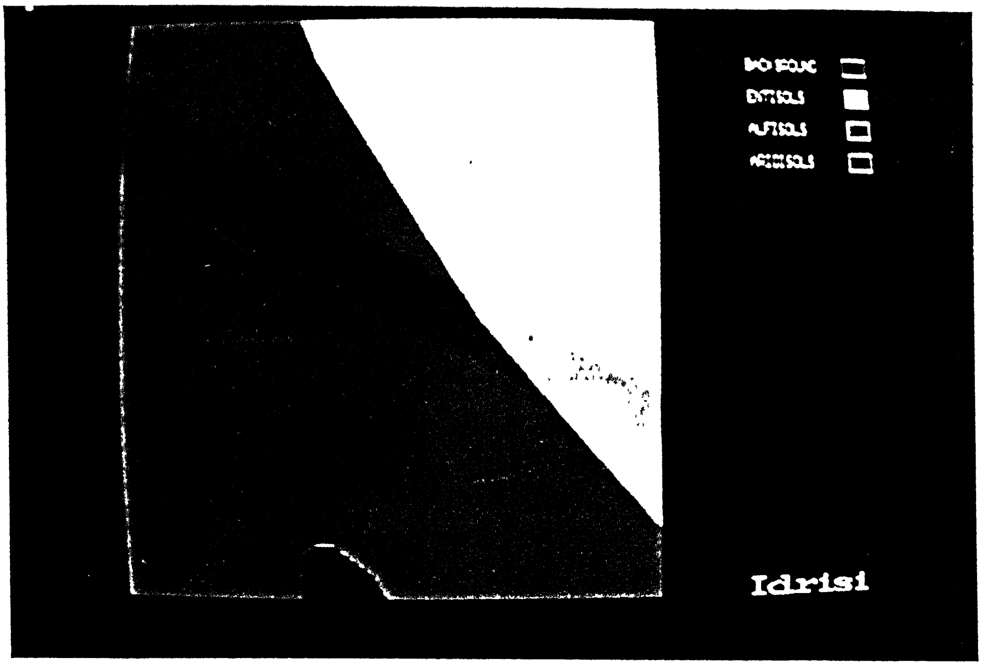

Plate A.1: Image of Raster Map Showing the Surface Soil Types

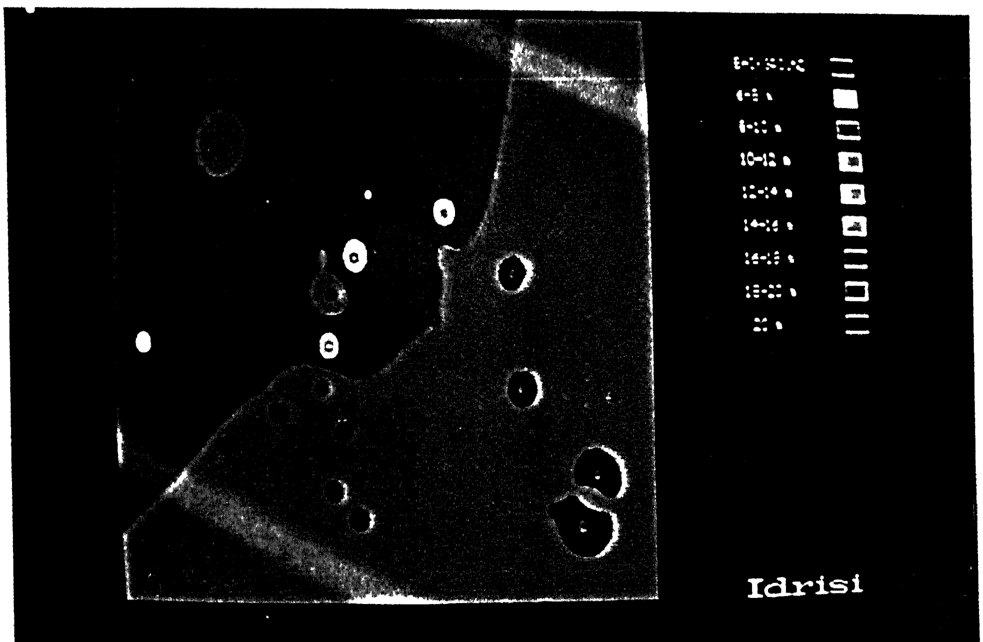

Plate A.2: Image of Raster Map Showing the Water Table Depths

Plate A.3: Image of Raster Map Showing the Distances from the Roads

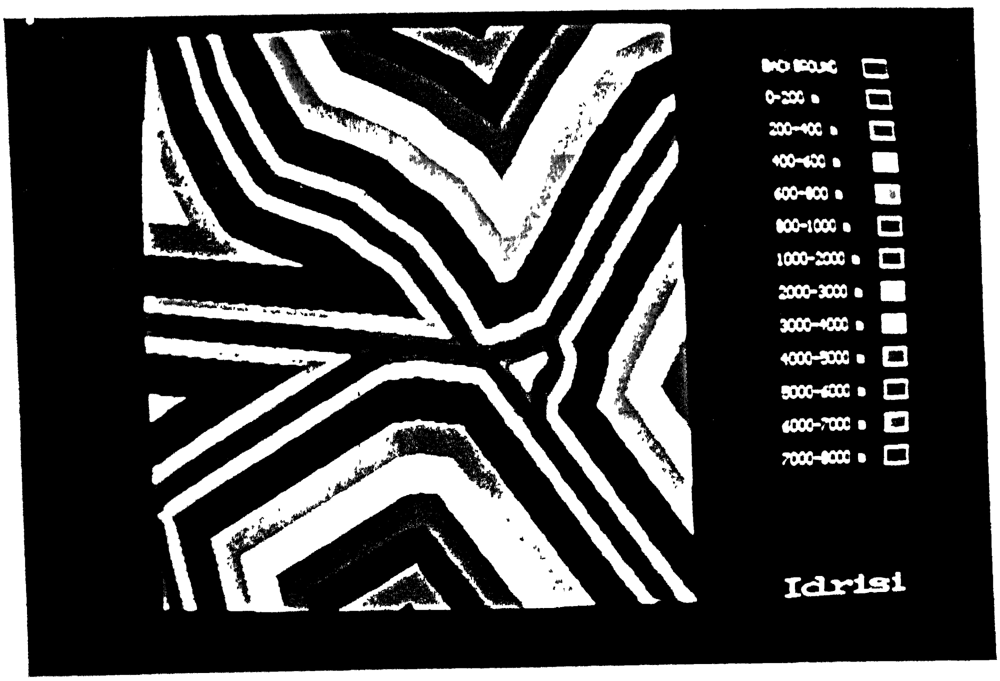

Plate A.4: Image of Raster Map Showing the Distances from the Railway Lines

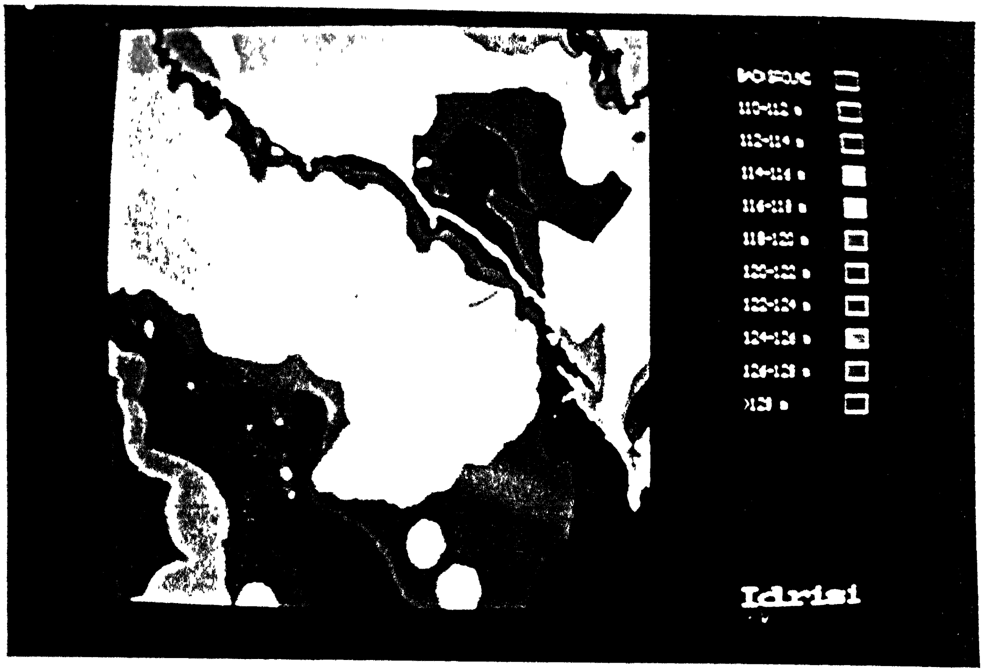

Plate A.5: Image of Raster Map Showing the Elevation above Mean Sea-Level

Plate A.6: Image of Raster Map Indicating Sites Suitable for Solid Waste Disposal